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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 724

Contribution from the Bureau of Public Roads.
LOGAN WALLER PAGE, Director

Washington, D. C. PROFESSIONAL PAPER December 21, 1918

DRAINAGE METHODS AND FOUNDATIONS FOR COUNTY ROADS

By

E. W. JAMES, General Inspector
VERNON M. PEIRCE, Assistant Engineer
CHARLES H. MOOREFIELD, Senior Highway Engineer

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The first essential feature of an improved road is adequate drainage. It is practically impossible to secure satisfactory results unless this feature be given proper attention. Another prime requirement, wherever a hard-surfaced road is to be constructed, is that a firm and unyielding foundation be provided. The purpose of this bulletin is to supply information concerning the proper methods of draining roadbeds, constructed of various kinds of soil, under different topographic conditions, and also to explain how foundations may be designed to suit the soil conditions, the road surface, and the system of drainage. Since the quality of the soil has such an important influence both on the proper method of drainage and on the proper type of foundation to be employed, it is desirable first to discuss briefly some of the most important characteristics of the different kinds of soils ordinarily encountered in highway construction.

PRIMARY SOILS.

The texture and structure are the principal properties of soils that determine the manner in which they should be drained and prepared for road foundations. These are important because of their effect on the permeability and capillarity of soils. For the purpose of this discussion, primary soils may be classified as gravel, sand, and clay; but it should be borne in mind that many of the secondary or mixed soils, because of their more general occurrence in connection with road-building connections, are equally important with these. This is especially true of some of the more clearly defined derivative or secondary soils such as loam, marl, gumbo, hardpan, etc. Where a soil is composed of two different materials, mixed in such proportions that its character is decidedly intermediate, it may be designated

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conveniently by naming both materials, as sand-clay, sand-gumbo, gravelly-clay, etc.

Clay.—Clay is a soil of very fine texture which results from the complete disintegration of rocks or minerals. Pure clay is very retentive of water and becomes plastic and unstable when wet. It is very difficult to drain, and, on that account, when it occurs in the subgrade of a road, the system of drainage should be designed with a view to preventing water from reaching the subgrade rather than to draining water from the clay. Most clays as they occur in nature contain more or less sand or gravel, which has a stabilizing effect by making the clay more easily drained and by furnishing a combination of mechanically interlocking grains. A mixture containing about 50 per cent each of clay and gravel or coarse sand often makes an excellent soil of which to construct roadbeds. Such a soil, in addition to being easily drained, has less "capillarity" than clay, and consequently does not need to be drained to so great a depth in order to prevent water from rising to the surface. Furthermore, it is moderately stable, even when wet.

Sand.—Sand is made up of granular particles of mineral or stone which occur in nature and which will pass a ¼-inch mesh screen. Particles which are too large to pass such a screen are called gravel. Nearly all natural sand consists of particles which are composed principally of quartz, individually very hard and durable. There is no coherence between the different grains, however, and soils composed principally of sand are unstable, unless properly confined and protected from undermining, in which case a good quality of sand may make an excellent subgrade for some types of road crusts and for practically any kind of foundation. Sandy soils usually require very little drainage except when the sand is mixed with a considerable percentage of fine silt. Sand so fine and evenly graded that it becomes saturated readily with water and remains so for more or less lengthy periods is called quicksand and has little dependable stability.

Loam.—A mixture of soil composed of clay or sand and a considerable percentage of decayed vegetable matter is called loam. All such soils usually contain both clay and sand in greater or less amount, and the quality of the loam for road-building purposes is largely dependent on the proportion in which the sand and clay are present. Most loams are drained comparatively easily, but are subject to the disadvantage that the vegetable matter they contain may be incompletely decomposed and subsequent decomposition eventually may cause more or less settlement and shrinkage.

Gravel.—Gravel is made up of small angular or rounded particles of stone which occur in nature and which are sufficiently large to be retained on a ¼-inch mesh screen. Gravelly soils are distributed widely in the United States and vary greatly in quality. In general,

when a soil contains as much as 40 or 50 per cent of gravel and sufficient clay or other bonding material to hold the particles of stone together it proves very satisfactory as a material for a roadbed, because it is drained easily and is very stable when compacted.

Marl.—Marl is a clay containing a large percentage of carbonate of lime. Frequently it contains shell fragments and nodules of chalk or silica, and other materials. It grades into calcareous clay on the one hand and into argillaceous limestone on the other, and its quality for road-building purposes varies to a considerable extent. In general this material has few advantages over ordinary clay for use in constructing a roadbed unless the percentage of lime carbonate be sufficiently high to give the material, when compacted, approximately the character of limestone.

Gumbo.—Gumbo is essentially clay or silt containing a high percentage of decayed vegetable matter and a very low percentage of sand. It has a very strong tendency to absorb and hold water, and therefore is hard to drain. If drained properly it may make a fair subgrade on which to place the foundation of a road, but it has comparatively a very low bearing value, and where used as the foundation the design should be such as to give a greater distribution of concentrated loads than is necessary with most other soils.

DRAINAGE.

In the design of a road the drainage structures are planned to take care of water under three general conditions: (1) The rain that falls on the road surface or grade, (2) the rain that falls on contiguous land and flows in accumulated volume toward the road, and (3) ground water from any mediate or immediate source. The structures commonly used to provide drainage and meet these conditions are longitudinal side ditches, usually parallel or approximately parallel to the center line; intercepting ditches to accommodate water whose approach so close to the roadway as the side ditches is likely to cause injury; lateral ditches or culverts to conduct accummulated water away from or under the road; and subdrains.

The side ditches are primarily to care for water flowing from the road surface and consequently are placed close to the surface or made a part of it, and their use is so general that it is universal practice to incorporate them into the design of the road cross section. If they actually are made a part of the surface, or an extension of it, they take the form of gutters. As gutters, their effect is not entirely the same as when constructed in the form of a ditch, as in the former case they do nothing toward draining the soil of the roadway, while as ditches they frequently reach such effective depth, as the result of cutting and filling along the grade, that they not only serve to carry away surface water but also do more or less toward lowering the water table under the traveled way.

Intercepting ditches also are usually approximately parallel to the center line but are more remote, often being placed outside of grading lines as berm ditches. Not infrequently intercepting ditches, on account of the immediately local conditions, are constructed so close to the roadway that they can be incorporated into the general cross section, but in such cases their design is independent of the other cross-section details, except as limited by them. Extreme cases of this last condition exist when a road is constructed close to a drainage ditch or irrigation canal, or when, as has occurred not infrequently, the spoil bank of such a canal is used as a road grade. In such cases the side ditch is omitted sometimes on the side toward the intercepting drainage ditch, or a gutter design is used and the flow in the gutter frequently turned into the larger channel. Lateral or cross drains, whether involving the construction of culverts or not, are to divert the flow from any longitudinal drain into a natural drainage channel. If this diversion involves crossing the center line it usually requires a culvert. If it does not cross the center line open lateral ditches are used. Subdrains are used to collect and carry to a suitable outfall water that exists or may accumulate periodically in the soil beneath the road surface or grade. Their use, design, and location depend on the presence of ground water and on the nature of the soil. A retentive impervious stratum underlying a road may prevent the downward percolation of surface water to such an extent as to do injury by saturating the soil, or the presence of springs or other flowing ground water may require their use. In general, subdrains are employed for three purposes appropriate to the conditions existing. They are used to divert springs or confined streams of underground water; to intercept the flow of underground water in the form of general seepage from sources more or less distant; and to lower the water table in places where the nature of the soil causes such water to rise too close to the surface to permit of securing adequate bearing values in the soil.

These various forms of drainage structures may be grouped into two classes according as they provide for surface or subsurface drainage. Obviously, as between the classes, the distinction is reasonably sharp, although, as pointed out, side ditches sometimes serve to lower the water table; but the distinctions between the various uses of the two types with regard to their respective purposes is often, if not generally, impossible of clear definition. This is true especially of subdrains. No matter what condition has led to the design and use of a subdrain, if occasion arises it may act in all of its common capacities.

Further, these types of drainage structures must be grouped and interrelated so as to produce the effect desired under the existing conditions. The drainage problem, especially as affecting foundations, is essentially a local one. This is apparent in some of the

older States where the system of State roads has changes in the foundation design at frequent intervals; and is, of course, doubly apparent from the location and relation of the constantly changing units of the surface drainage system.

In order, therefore, to plan intelligently a system of drainage for any particular road, it is necessary to take into consideration not only the local character of the soil composing the roadbed, but also the topography of the adjacent land, the amount and rate of rainfall, and the availability of different materials suitable for use in constructing drains.

Topography has a very important influence in determining the relation of surface and subdrainage, and when one or the other drainage is more practicable. When the topography is such that the side ditches can be given a grade of as much as 1 or 2 per cent, subsurface drains seldom are necessary, except in unusually heavy clay soils and where springs occur; while, on the other hand, where the grade is level or nearly so, subsurface drainage may be required when the soil composing the roadbed otherwise would be comparatively easy to drain.

The topography of the land adjacent to a road determines to a considerable extent also the necessary capacity of the surface drains and the location of the appropriate structures. Watersheds having a fan shape, for example, empty the water which falls upon them into the drainage structures much more rapidly than long, narrow drainage areas, because of the difference in time required for water from the more remote parts of the area to reach the outlet. Steep slopes deliver water at the outlets much more rapidly than flat areas; and impervious soils, by refusing to absorb precipitation, deliver greater percentage of rainfall at the outlet.

The amount and rate of rainfall are the primary factors in determining the quantity of water drained off from the land, or "run-off," as it is called. Since the capacity necessary for a given drain is fixed by the maximum run-off which it will be called upon to accommodate, a knowledge of the rainfall is essential in planning a system of surface drainage. In the design of surface drains and culverts it is usually necessary to consider only the maximum rate of rainfall and the maximum duration of time through which individual rains continue, but in the case of subsurface drains the duration of a wet season and its effect on the accumulation of ground water also may be of importance. During the most extreme local storms occurring in some sections of the United States the precipitation sometimes amounts to 7 or 8 inches in 24 hours, and in a few cases has been known to exceed an inch in one hour. Where the topographic conditions are favorable to a rapid run-off, such as is generally the case with an improved road, from 80 to practically

100 per cent of the total precipitation may be drained from the watershed during a storm. The extreme rate occurs principally in paved cities in the closely built up business sections, but 80 per cent run-off may occur in very steep, impervious or compactly shaped watersheds. Under the worst conditions, therefore, it may be necessary to design surface drains and culverts with capacity sufficient to remove about 6 inches of water from a watershed in 24 hours and to take care of an extreme precipitation of about 1 inch in 1 hour. Under other circumstances, the maximum rate of rainfall may be considerably less than that mentioned above, and the maximum run-off during storms may be only about 15 or 20 per cent of the total precipitation on the watershed, though this low run-off does not apply often to road drainage.

CAPACITY OF DRAINS.

The amount of water required to cover an acre of land to a depth of 1 inch is 3,630 cubic feet. If the maximum rainfall and run-off and the area to be drained can be determined, therefore, the total volume of water which a given drain should be designed to accommodate can be computed readily. From what has been said, it is apparent that any estimate of the run-off necessarily will be a rather rough approximation, and due allowance on the safe side always should be made as a safeguard against possible inaccuracies in such estimates.

The size of drain necessary to carry a given volume of water in a given time may be estimated from the formula $v=c\sqrt{rs}$, in which v= mean velocity of water; r=hydraulic mean radius of the drain; s= the slope of the drain; and c=a coefficient, the value of which depends on the character of the surface of the drain, the slope, and the hydraulic mean radius. Kutter's formula is the one generally considered most reliable for determining the value of the coefficient, c. According to this formula when English units are used,

$$C=\frac{41.6+\frac{.00281}{s}+\frac{1.811}{n}}{1+\frac{\left(41.6+\frac{.00281}{s}\right)n}{\sqrt{r}}}$$

in which s=slope ratio of drain; r=hydraulic mean radius in feet, and n=a constant which depends on the character of the surface of the drain. Under average conditions the value of n may be assumed as follows: for open ditches, 0.025 to 0.040; for cobble gutters, 0.020 to 0.035; for concrete gutters, 0.015 to 0.020; for tile pipe, 0.015. The following tables have been computed by means of the above formulæ especially for use in planning drainage systems.

VELOCITY-QUANTITY TABLE NO. 1.—*For earth ditch having cross section shown in figure 1.*

[Value of "*n*" ranges from 0.025 to 0.040. Value used in this table is 0.030. W is width of bottom of ditch, in feet. D is depth of water flowing in ditch, in inhces. A is area of wetted cross section, in square feet. R is hydraulic radius. C is from Kutter's formula for same. V is velocity in feet, per second. Q is discharge, in thousand cubic feet per hour. Velocities above and to the left of the heavy line are safe for ordinary soils.]

W	D	A	R	C	Slope, in feet per foot.																	
					0.001		0.003		0.005		0.01		0.02		0.03		0.04		0.05		0.07		0.10	
					V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
0.5	2	0.133	0.1132	21.4	0.23	0.110	0.39	0.187	0.51	0.244	0.72	0.345	1.01	0.483	1.25	0.598	1.44	0.689	1.61	0.770	1.91	0.914	0.228	1.090
.5	4	.362	.1965	26.6	.37	.482	.64	.834	.84	1.090	1.18	1.538	1.66	2.165	2.04	2.657	2.36	3.070	2.64	3.440	3.12	4.060	3.72	4.850
.5	6	.688	.273	29.7	.50	1.230	.90	2.220	1.10	2.720	1.50	3.720	2.20	5.450	2.70	6.680	3.10	7.670	3.50	8.670	4.20	10.410	4.90	12.150
.5	12	2.250	.500	36.5	.80	6.480	1.40	11.340	1.80	14.580	2.60	21.050	3.70	29.970	4.50	36.450	5.20	42.120	5.80	46.990	6.80	55.050	8.10	65.600
.5	18	4.690	.716	40.7	1.00	16.860	1.90	32.100	2.40	40.500	3.40	51.400	4.90	82.700	6.00	101.400	6.90	116.500	7.70	130.000	9.10	153.580	10.80	168.600
.5	24	8.000	.932	44.1	1.30	37.450	2.30	66.200	3.00	86.420	4.30	123.800	6.00	172.900	7.40	213.120	8.50	244.900	9.50	273.600	11.30	325.440	13.40	385.820
1.0	2	.216	.128	22.3	.25	.193	.43	.340	.57	.443	.80	.621	1.13	.878	1.39	1.075	1.60	1.243	1.79	1.392	2.12	1.647	2.53	1.963
1.0	4	.529	.225	27.8	.42	.800	.71	1.350	.93	1.774	1.32	2.510	1.86	3.540	2.28	4.340	2.63	5.010	2.95	5.620	3.49	6.640	4.17	7.930
1.0	6	.940	.310	31.3	.60	2.030	1.00	3.380	1.20	4.060	1.70	5.750	2.50	8.460	3.00	10.150	3.50	11.820	3.90	13.200	4.60	15.560	5.50	18.610
1.0	12	2.750	.510	36.5	.80	7.920	1.40	13.850	1.80	17.820	2.60	25.740	3.70	36.640	4.50	44.580	5.20	51.470	5.80	57.420	6.90	68.310	8.20	81.180
1.0	18	5.440	.770	41.6	1.20	23.500	2.00	39.180	2.60	50.910	3.60	70.500	5.10	99.900	6.30	123.400	7.30	143.000	8.20	160.580	9.70	189.960	11.50	225.170
1.0	24	9.000	.999	44.0	1.40	45.360	2.40	77.800	3.20	103.700	4.50	145.800	6.30	204.720	7.80	252.720	8.90	288.360	10.00	324.000	11.80	382.320	14.10	456.840
2.0	2	.383	.144	23.3	.27	.385	.48	.660	.62	.854	.88	1.219	1.25	1.722	1.53	2.108	1.77	2.438	1.98	2.728	2.34	3.220	2.79	3.850
2.0	4	.863	.257	29.2	.47	1.452	.81	2.520	1.04	3.232	1.48	4.600	2.09	6.480	2.55	7.920	2.96	9.200	3.33	10.300	3.91	12.160	4.68	14.520
2.0	6	1.440	.360	32.8	.60	3.110	1.10	5.700	1.40	7.260	2.00	10.370	2.80	14.520	3.40	17.620	3.90	20.220	4.00	22.800	5.20	26.950	6.20	32.140
2.0	12	3.750	.620	39.3	1.00	13.500	1.70	22.950	2.20	29.700	3.10	41.810	4.30	58.000	5.40	72.830	6.20	83.620	6.90	93.150	8.20	110.700	9.80	132.300
2.0	18	6.940	.860	42.9	1.30	32.470	2.22	54.950	2.80	69.950	4.00	99.920	5.60	139.880	6.90	172.360	8.00	199.840	8.90	222.360	10.50	262.330	12.60	314.750
2.0	24	11.000	1.090	45.5	1.40	59.260	2.60	102.920	3.30	132.680	4.70	187.500	6.70	264.320	8.20	324.720	9.50	375.700	10.60	419.800	12.60	498.960	15.00	594.000
3.0	2	.550	.150	23.7	.29	.594	.50	.996	.65	1.284	.92	1.817	1.29	2.552	1.59	3.150	1.83	3.620	2.05	4.070	2.43	4.813	2.90	5.742
3.0	4	1.197	.276	30.0	.50	2.152	.86	3.720	1.12	4.800	1.57	6.787	2.22	9.570	2.72	11.740	3.15	13.580	3.53	15.200	4.18	18.000	4.98	21.480
3.0	6	1.940	.380	33.4	.70	4.890	1.10	7.680	1.40	9.780	2.10	14.660	2.70	18.850	3.60	25.120	4.00	27.930	4.60	32.120	5.50	38.400	6.50	45.380
3.0	12	4.750	.680	40.2	1.10	18.800	1.80	30.780	2.30	39.300	3.30	56.400	4.60	78.610	5.70	97.410	6.60	112.860	7.40	126.540	8.70	148.800	10.40	177.840
3.0	18	8.440	.950	44.3	1.40	42.530	2.40	72.900	3.10	94.200	4.40	133.670	6.20	188.350	7.50	227.100	8.60	260.410	9.70	294.730	11.50	349.420	13.60	413.220
3.0	24	13.000	1.170	46.7	1.60	74.880	2.80	131.050	3.60	168.480	5.10	238.680	7.10	332.280	8.80	411.840	10.10	472.680	11.30	528.840	13.40	627.120	16.00	748.800
3.0	30	18.400	1.390	48.9	1.80	119.230	3.10	205.340	4.10	271.580	5.80	384.190	8.10	536.540	10.00	662.400	11.50	761.760	12.90	854.500	15.30	1,013.470	18.20	1,205.570
3.0	36	24.800	1.640	51.1	2.10	187.480	3.60	321.400	4.60	410.680	6.60	589.250	9.20	821.370	11.30	1,008.860	13.10	1,169.570	14.60	1,303.490	17.30	1,544.540	20.60	1,839.170

Velocity-Quantity Table No. 1A.—*For earth ditch having cross section shown in figure 2.*

[Value of "*n*" ranges from 0.025 to 0.040. Value of "*n*" used in this table is 0.030. D is depth of water flowing in ditch, in inches. A is area of wetted cross section, in square feet. R is hydraulic radius. C is from Kutter's formula for same. V is velocity, in feet per second. Q is discharge, in thousand cubic feet per hour. Velocities above and to the left of the heavy line are safe for ordinary soils.]

D	A	R	C	Slope, in feet per foot.																			
				0.001		0.003		0.005		0.01		0.02		0.03		0.04		0.05		0.07		0.10	
				V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
2	0.074	0.076	18.5	0.16	0.044	0.28	0.075	0.36	0.096	0.51	0.136	0.71	0.189	0.87	0.232	1.01	0.269	1.13	0.301	1.34	0.357	1.60	0.426
4	.305	.155	24.0	.30	.33	.51	.564	.66	.727	.94	1.03	1.32	1.45	1.62	1.78	1.89	2.07	2.12	2.32	2.50	2.74	2.96	3.25
6	.69	.23	28.1	.42	1.042	.73	1.812	1.01	2.51	1.35	3.35	1.73	4.295	2.33	5.785	2.70	6.70	3.01	7.47	3.50	8.699	4.20	10.42
8	1.22	.31	31.3	.55	2.41	.95	4.16	1.21	5.30	1.74	7.54	2.46	10.80	3.01	13.22	3.49	15.34	3.90	17.12	4.62	20.03	5.50	24.15
12	2.75	.46	35.6	.76	7.52	1.30	12.86	1.70	16.83	2.40	23.75	3.40	33.65	4.20	41.55	4.80	47.50	5.40	53.42	6.40	63.38	7.60	75.2
18	6.18	.70	40.5	1.07	23.81	1.80	40.05	2.40	53.40	3.40	75.61	4.80	106.75	5.90	131.22	6.80	151.30	7.60	169.10	9.00	200.05	10.70	238.10

Velocity-Quantity Table No. 1B.—*For earth ditch having cross section shown in figure 3.*

[Notation the same as for Table 1A.]

D	A	R	C	Slope, in feet per foot.																			
				0.001		0.003		0.005		0.01		0.02		0.03		0.04		0.05		0.07		0.10	
				V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
1	0.047	0.041	14.1	0.09	0.015	0.15	0.025	0.20	0.034	0.28	0.047	0.40	0.067	0.49	0.083	0.56	0.094	0.63	0.106	0.75	0.126	0.89	0.150
2	.187	.074	18.0	.15	.101	.27	.182	.35	.236	.49	.330	.69	.465	.85	.572	.98	.661	1.10	.745	1.30	.876	1.55	1.045
3	.421	.110	21.2	.22	.333	.38	.576	.50	.757	.70	1.061	.94	1.425	1.21	1.822	1.40	2.12	1.57	2.35	1.86	2.82	2.21	3.34
4	.750	.148	23.0	.28	.756	.49	1.323	.63	1.700	.89	2.41	1.25	3.38	1.53	4.13	1.77	4.78	1.97	5.32	2.35	6.35	2.80	7.56
5	1.172	.189	26.1	.36	1.52	.62	2.620	.80	3.370	1.14	4.81	1.60	6.75	1.96	8.26	2.27	9.58	2.54	10.72	3.01	12.70	3.59	15.15
6	1.689	.244	29.3	.46	2.78	.79	4.82	1.02	6.22	1.58	8.80	2.04	12.40	2.50	15.23	2.90	17.61	3.25	19.72	3.84	23.33	4.57	27.80

Velocity-Quantity Table No. 2.—*For cobble gutter of design shown in figure 4.*

[Value of "*n*" ranges from 0.0150 to 0.030. Satisfactory value of "*n*" is 0.018 for cemented cobble gutter and 0.030 for rough cobble type. That used in this table is 0.030. D is depth of water, in inches. A is area of wetted cross section, in square feet. R is hydraulic radius, in feet. C is from Kutter's formula for the same. V is velocity, in feet per second. Q is discharge, in thousand cubic feet per hour.]

D	A	R	C	Slope, in feet per foot.																	
				0.001		0.003		0.005		0.01		0.02		0.03		0.04		0.05		0.07		0.10	
				V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
2	0.15	0.109	20.7	0.21	0.113	0.38	0.205	0.48	0.259	0.69	0.372	0.97	0.524	1.18	0.637	1.37	0.740	1.53	0.826	1.81	0.984	2.20	1.190
3	.34	.164	24.6	.31	.380	.55	.673	.70	.856	1.00	1.220	1.40	1.710	1.72	2.102	1.99	2.435	2.23	2.730	2.64	3.260	3.15	3.850
4	.60	.217	27.5	.40	.864	.70	1.512	.90	1.943	1.28	2.765	1.85	3.990	2.20	4.750	2.56	5.530	2.87	6.190	3.39	7.320	4.05	8.740
6	1.34	.321	31.7	.57	2.750	.98	4.730	1.27	6.130	1.79	8.640	2.53	12.210	3.10	14.950	3.59	17.340	4.02	19.400	4.75	22.920	5.67	27.370

Velocity-Quantity Table No. 3.—*For concrete gutter of design in figure 5.*

[Values of "*n*" range from 0.0149 to 0.0188. Value used in this table is 0.015. D is depth of water, in inches. A is area of wetted cross section, in square feet. R is hydraulic radius, in feet. C is from Kutter's formula for the same. V is velocity, in feet per second. Q is discharge, in thousand cubic feet per hour.]

D	A	R	C	Slope, in feet per foot.																	
				0.001		0.003		0.005		0.01		0.02		0.03		0.04		0.05		0.07		0.10	
				V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
2	0.150	0.109	55.6	0.58	0.313	1.01	0.543	1.29	0.700	1.83	0.991	2.58	1.398	3.18	1.715	3.67	1.983	4.11	2.220	4.87	2.628	5.79	3.133
3	.340	.164	62.8	.80	.983	1.39	1.710	1.77	2.200	2.51	3.100	3.59	4.390	4.40	5.380	5.09	6.220	5.70	6.970	6.74	8.240	8.04	9.830
4	.600	.217	69.0	1.01	2.190	1.75	3.803	2.27	4.910	3.20	6.940	4.50	9.800	5.57	12.020	6.43	13.890	7.20	15.560	8.45	18.400	10.16	21.950
6	1.340	.321	76.9	1.38	6.640	2.39	11.520	3.08	14.850	4.36	21.020	6.14	29.650	7.55	36.400	8.72	42.060	9.76	47.100	11.54	55.740	13.76	66.440

VELOCITY-QUANTITY TABLE NO. 4.—*For tile pipe with smooth joints.*

[Value of "*n*" used is 0.015. D is diameter of pipe in inches. A is wetted area of cross section of pipe in square feet. R is mean hydraulic radius in feet. C is coefficient taken for S equal to 0.001. Q is discharge in thousand cubic feet per hour. The pipe is assumed to run 0.95D full.]

D	A	R	C	Slope, in feet, per foot.									
				0.001	0.003	0.005	0.01	0.02	0.03	0.04	0.05	0.07	0.10
				Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
4	0.086	0.095	53.9	0.162	0.281	0.363	0.512	0.722	0.886	1.025	1.146	1.356	1.61
6	.193	.143	58.6	.485	.841	1.085	1.534	2.162	2.652	3.070	3.438	4.065	4.848
8	.343	.191	64.8	1.104	1.915	2.470	3.500	4.928	6.080	6.990	7.813	9.270	11.050
12	.771	.287	73.7	3.452	5.990	7.730	10.925	15.410	18.910	21.870	24.480	28.950	34.520
15	1.200	.358	77.9	6.360	11.030	14.230	20.130	28.380	34.820	40.260	45.100	53.350	63.600
18	1.734	.430	81.4	10.520	18.240	23.550	33.300	46.950	57.600	66.600	74.600	88.200	105.250

It will be noted that the trapezoidal open ditch has been assumed in computing capacity. This is by far the commonest type used in cross-section designs, although the dimensions vary within rather wide limits. This is supplemented by two ditches of the V type, one having a very flat slope. These indicate the transition in earth from the trapezoidal or dug ditch to the gutter type, which often can be made with the ordinary road grader. The common rectangular or "square" ditch, so frequently seen in some localities, especially in the southeastern part of the United States where sand clays abound, is not calculated. This type of ditch is not recommended for several reasons. In the first place there are very few soils that will stand with a vertical face, particularly if that face be presented to flowing water. Such materials as the loess of Adams County, Miss., and certain grades of sand clay in the Carolinas and Georgia are rare. Service tests indicate that such material will stand for years, but ordinarily nothing but a service test will disclose that characteristic, and no amount of examination appears to furnish sufficient data for a decision as to whether or not an earthy material may be counted upon to stand practically vertical. The safest assumption in design is to rely on no unusual qualities in the soil at hand and to construct a ditch on one of the approved designs used in the tables.

The V-shaped ditches have several favorable characteristics. They are not dangerous to traffic. They can be made with a grading machine and can be cleaned and maintained very largely with a grader, or for light work even with a drag. The highest velocity of flow in the ditch cross section occurs toward the side away from the road, and so the tendency to scour or wash, unless there be some disturbing obstruction, occurs first on the side away from the road and gives ample warning that attention is needed. These are the shapes that most closely approach common gutter design, and thereby lend themselves most readily to continued improvement by paving if the surface be advanced in type to warrant such a change.

The foregoing tables on page 7 are not applicable to short cross drains and culverts, because the condition of approach channels and outlets affect the capacity of these to a very great extent. Data for use in designing structures of this kind are furnished in other bulletins of the Bureau of Public Roads.

DESIGN OF SURFACE DRAINAGE.

Surface-drainage systems for roads consist of side ditches along road, paved gutters which are a development of side ditches and replace them, open intercepting ditches constructed to prevent water from reaching the road, and lateral or relief ditches to carry off the water which collects in the side ditches or in the intercepting ditches. Culverts and inclosed drains, which are constructed for the purpose of removing storm water from the side ditches or gutters, are essentially a part of the surface drainage system and are not to be confused with subdrains, which have an entirely different purpose.

CROWN.

The amount of crown which the surface of a road should be given in order to drain itself properly is very important in connection with surface drainage and one of the early elements of consideration in drainage design. But, since this feature is necessarily influenced by other considerations than efficient drainage, it will not be discussed at length in this paper. The Bureau of Public Roads has already published bulletins discussing the detailed design and construction of many types of improved road and reference may be had to these[1] in determining the amount of crown necessary for the various types.

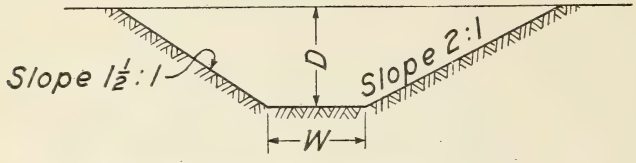
SIDE DITCHES.

Side ditches usually are necessary where roads are located in cuts or where they follow the natural surface of the ground. It is also frequently desirable to construct ditches approximately paralleling the road, even when in fill, in order to conduct water from a neighboring cut or berm ditch by a ready channel to some accessible natural drainage line. Tables 1A and 1B show the carrying capacity of ditches having various forms and slopes, and figures 1, 2, and 3 show the three cross-sectional shapes most commonly employed.

A ditch having the trapezoidal cross section shown in figure 1 has a greater carrying capacity for the same cross-sectional area, but unless the bottom be made relatively wide it erodes more easily than the ditches shown in figures 2 and 3. This section is adapted in general to locations where the slope is comparatively light and the amount of water to be drained is relatively large. For side ditches

[1] Office of Public Roads Bulletins 43 and 45; Yearbook separate 737.

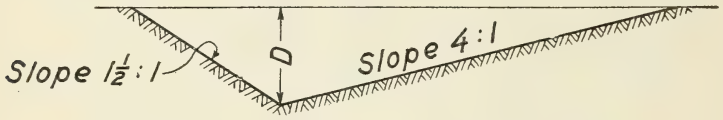
D is usually made from 1 foot to 1 foot 6 inches, with W sufficient to give the required capacity. Where the ditch is not located sufficiently far from the road to avoid danger to traffic, and the grade is steep, it may be desirable to increase W and diminish D, in order to secure the required cross-sectional area and at the same time prevent erosion.



SECTION OF EARTH DITCH

FIG. 1.

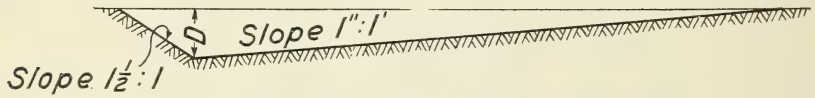
The section shown in figure 3 gives a ditch of comparatively small capacity, but the same amount of water flowing in a ditch of this shape will cause less erosion on steep grades than in a very narrow ditch of the cross section shown in figure 1. Another advantage of this wide, flat ditch is that it may be constructed easily and main-



SECTION OF EARTH DITCH

FIG. 2.

tained by means of a road grader, while the other types of ditches require more or less pick-and-shovel work. One of its principal disadvantages is that it must be extremely wide on light grades in order to carry any considerable quantity of water, and in deep cuts it may be very expensive to obtain the necessary width.



SECTION OF EARTH DITCH

FIG. 3.

Figure 2 shows a modification of the section shown in figure 3, which is intended to meet conditions intermediate between those described as being suited respectively to the other two sections.

From the velocity-quantity tables, pages 7 to 9, it is apparent that for a ditch of given cross section the velocity of flow is dependent upon (1) the quantity of water the ditch carries, and (2) the longitudinal slope of the ditch. The velocity which causes erosion

varies considerably with the character of the soil traversed by the ditch, and, since it is impracticable to describe soils in exactly comparable terms, no exact rules can be established for determining the safe velocity for water flowing in earth ditches. The heavy zigzag lines drawn through the tables are just below the maximum velocities which would ordinarily be considered safe for the most favorable soil conditions, and table 5 shows other safe velocities which may be assumed for given soil conditions.

TABLE 5.—*Safe maximum stream velocities for different soils and other materials.*

Kind of material.	Mean velocity in feet per second beyond which erosion is likely to occur.	Remarks.
Fine sand and silt	0.5 to 1.0	These values would apply to some alluvial soils.
Sandy loam, clay loam, and light clay	1.0 to 1.5	Average soil conditions.
Stiff clay and other firm soils (not subject to freezing).	1.5 to 3.0	These values should be used for only very resistant soils in warm climates.
Coarse gravel and crushed stone	3.0 to 5.0	These values apply to such materials as are ordinarily used for road crusts.
Cobble gutters sand filled	5.0 to 7.0	The sand filler would be retained only by virtue of the rough surface.
Cobble gutters grout filled	10.0 to 15.0	
Solid rock and concrete	15.0 to 25.0	

VELOCITY-QUANTITY TABLE NO. 6.—*For concrete gutter having cross section shown in figure 6B.*

[Range in values of "*n*" from 0.0149 to 0.0188. Value of "*n*" assumed for this table 0.015. D is depth of water flowing in gutter in inches. A is area of wetted cross section in square feet. B is mean hydraulic radius in feet. C is from Kutter's formula for the same. V is velocity in feet per second. Q is quantity in thousand cubic feet per hour.]

D	A	R	C	Slope, in feet per foot.																			
				0.001		0.003		0.005		0.01		0.02		0.03		0.04		0.05		0.07		0.10	
				V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
2	0.167	0.075	49.4	0.43	0.256	0.74	0.444	0.95	0.573	1.40	0.810	1.90	1.143	2.34	1.402	2.70	1.621	3.05	1.816	3.80	2.150	4.30	2.56
3	.375	.111	55.7	.59	.792	1.02	1.374	1.30	1.771	1.90	2.50	2.63	3.533	3.20	4.337	3.70	5.015	4.16	5.615	4.90	6.64	5.90	7.92
5	1.04	.192	66.5	.92	3.44	1.60	5.97	2.05	7.69	2.90	10.89	4.10	15.35	5.00	18.84	5.80	21.78	6.50	24.40	7.70	28.85	9.20	34.40
6	1.50	.23	70.0	1.06	5.73	1.84	9.94	2.38	12.82	3.36	18.13	4.73	25.57	5.80	31.38	6.70	36.27	7.50	40.60	8.90	48.03	10.60	57.27

VELOCITY-QUANTITY TABLE NO. 7.—*For concrete gutter having cross-section shown in figure 6A.*

[Notation is same as for Table 6.]

D	A	R	C	Slope, in feet per foot.																			
				0.001		0.003		0.005		0.01		0.02		0.03		0.04		0.05		0.07		0.10	
				V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
1	0.083	0.04	39.3	0.25	0.071	0.43	0.129	0.56	0.166	0.79	0.235	1.11	0.332	1.36	0.407	1.58	0.471	1.77	0.528	2.08	0.624	2.49	0.744
2	.334	.08	50.5	.46	.552	.80	.957	1.03	1.235	1.51	1.718	2.05	2.463	2.52	3.021	2.90	3.493	3.27	3.923	4.20	4.630	4.59	5.52
3	.750	.119	57.0	.62	1.677	1.08	2.910	1.39	3.753	1.97	5.309	2.77	7.480	3.39	9.148	3.94	10.62	4.41	11.89	5.22	14.07	6.22	16.78
4	1.334	.16	62.3	.78	3.783	1.36	6.56	1.75	8.46	2.47	11.97	3.49	16.87	4.28	20.70	4.95	23.94	5.54	26.81	6.55	31.72	7.81	37.82
6	3.00	.239	70.7	1.09	11.81	1.89	20.48	2.46	26.41	3.46	37.34	4.88	52.67	5.94	64.61	6.92	74.71	7.75	83.70	9.17	99.00	10.94	118.10

As an example of how the tables may be used, consider a side ditch of the cross section shown in figure 3, in moderately stable loam soil and let it be assumed that the ditch will drain the surface on each side for an average distance of 12 feet from the center, or that the total width drained is 24 feet. Also assume the maximum rainfall at 1 inch per hour, the maximum run-off at 100 per cent, the allowable velocity in the ditch at 1 foot per second, and the longitudinal slope of the ditch at 0.05 or 5 per cent. From table 1B we see that in order for the velocity not to exceed 1 foot per second, the depth of water in the ditch must not exceed about $1\frac{3}{4}$ inches, and that this depth fixes the capacity of the ditch at about 500 cubic feet per hour. Under the given assumptions, the allowable quantity of water would flow into the ditch in a distance of 250 feet, and, if a greater length of ditch must be drained without the water being turned off, some provision for protecting the ditch from erosion should be made below the 250-foot point.

In practice it frequently will be necessary to modify the computations by taking into consideration such contingencies as changes in the grade or curves in the alignment of the ditch, or the matter of water being turned into the ditches from intersecting roads or adjacent fields. Where the grade of a ditch flattens out in descending a hill, for example, the velocity of the water will be checked where the change occurs, and a part of whatever soil it has in suspension will be deposited. Curves in alignment produce a tendency for the water to cut sideways, away from the center of the curve, and for this reason water following along the inside ditch of a curved roadway is very liable to erode the shoulder, and eventually may undermine the road crust, unless provision be made to prevent this. In general, wherever there are marked changes in grade, it is good design to proportion the ditches accordingly, especially where a descending grade flattens out or a curve occurs in the alignment. This is a detail quite commonly neglected, but by observing it the velocity of the flow can be maintained sufficiently uniform to prevent both the deposit of sediment and the erosion of the ditch or grade. The practice of turning into side ditches water from adjacent fields and intersecting roads is very objectionable, especially on steep grades, and usually can be avoided. Where it can not be avoided, ample allowance for the additional water should be made in the computations.

In order to supplement the data contained in the tables a limited number of observations have been made on roads in several localities, with a view to ascertaining just how the erosion of side ditches actually is affected by different conditions of soil and grade. The sections of road selected for study were all so situated that the area drained by the side ditches consisted of only the roadway and the excavation slopes formed in grading the road. Studies were made in

Maryland, Ohio, North Carolina, and South Carolina, but the data so far secured do not warrant any attempt to take the locality into account in presenting the results. The conclusions which seem warranted at present may be stated briefly as follows:

1. Except where the soil is sandy, the run-off, so far as the roadway and slopes are concerned, should be assumed as 100 per cent of the rainfall.

2. For sandy soils the run-off varies considerably. Where the soil is as much as 3 or 4 feet in depth and the grade does not exceed 5 or 6 per cent, it appears that the surface run-off may usually be entirely neglected. For less depths of sandy soil the run-off may for present purposes be assumed as inversely proportional to the depth. This does not apply to soils consisting of very fine sand with a large percentage of silt, as such soils may be almost impervious to water and always erode very easily.

3. The power of soils to resist erosion is much less when the ditch is first constructed than later. This is true especially where vegetation is allowed to grow in the ditches.

4. Although the velocity of flow is independent of the length of ditch, the length affects the quantity of water passing any given point, and consequently affects the amount of erosion. Further, the tendency to erode on the steep section of a ditch, however short, will be practically the same as if the steep grade prevailed throughout the length drained.

5. The relative carrying capacity of differently shaped ditches appears to be indicated with a fair degree of accuracy in the velocity-quantity tables given on pages 7 and 8, though the observed data bearing on this point are not sufficiently complete to warrant an exact comparison.

6. It is theoretically possible to construct an earth side ditch of such cross section as to carry any given amount of water on any given grade without erosion. But the impracticability of widening the ditch indefinitely and the difficulty of maintaining a wide flat-bottomed ditch necessary to produce this result in practice usually serve to place a rather low limit on the capacity.

7. Where ditches of ordinary cross section are employed, the most satisfactory way to prevent erosion is to provide outlets for the water at proper intervals, to be determined in the manner already discussed.

8. Where for any reason outlets for the ditches can not be provided at proper intervals it usually is much more satisfactory to provide a paved gutter than to attempt to widen the ditch beyond the limits already described as conforming to good practice. The main reason for this is that a wide ditch, though properly designed and constructed, easily may become partially obstructed, so that the channel is effectively narrowed and erosion results. Once started this may increase very rapidly.

9. Side ditches may be protected to some extent from erosion by means of "bars," "breakers," or "drops" constructed across the ditch at such intervals that the slope from the bottom of one breaker to the top of the next one below does not exceed what is allowable for the soil and maximum flow of water involved. Such breakers frequently have been constructed of wood and sometimes of stone or concrete. Plate I is a photograph illustrating the method employed. It should be noted that where drops are used much difficulty is experienced sometimes in preventing the water from finding its way around their ends and cutting into the shoulders or banks.

10. Where doubt exists as to the necessity for employing a paved gutter it frequently is permissible to withhold decision until time can demonstrate whether or not the side ditch is adequate. This is true especially where the

gutter would be made of different material from the road crust, and constructed at a different time or by a different force of laborers.

11. The maintenance of side ditches consists in keeping them free from obstructions, and in reshaping them whenever this is desirable in order to prevent erosion. While a limited amount of vegetation may be advantageous to ditches on steep grades, it should not be such as to interfere seriously with the flow of water in the ditch. Where drops are employed they should receive frequent attention to see that they are not being undermined and that the water is not cutting around them. The design of drops sometimes calls for the use of brush, logs, saplings, cut stakes, etc., as these often are the only inexpensive local materials available in rural sections. While such designs, if carefully considered, may produce drops effective for a considerable period, their use is not recommended because of the great danger that the drop will break up under stress of unusual conditions and the floating parts seriously obstruct the ditch.

12. The following examples have been selected from notes regarding some of the existing side ditches which have been observed:

Example No. 1.—Side ditch on Rock Point road, Charles County, Md.:

Age of road, 1½ years.
Original shape of ditch, flat V.
Width of roadway, 24 feet.
Width of gravel surface, 15 feet.
Average width drained by side ditch, including slope, 25 feet.
Character of soil, very light clay.
Slope of ditch (grade), 2 per cent.
Length from summit to where erosion begins, 400 feet.
Ditch empties into cross drain at 500 feet.

Example No. 2.—Same road and same conditions as example No. 1, except slope of ditch is 3 per cent:

Length from summit to where erosion begins, 200 feet.
Ditch maintained with considerable difficulty below the 200-foot point by means of wooden breakers.

Example No. 3.—Side ditch on Owings-Prince Frederick road, Calvert County, Md.:

Age of road, 4 years.
Original shape of ditch, flat V.
Width of roadway, 23 feet.
Sandy-clay surface.
Average width drained by side ditch including slope, 22½ feet.
Character of soil, very light clay with small percentage of fine sand.
Slope of ditch (grade), 6 per cent.
Length from summit to where erosion begins, 100 feet.
At 300 feet the ditch has eroded 1 foot below the original section, and below 550 feet it is maintained with great difficulty by means of wooden breakers. Below 650 feet, in fact, the entire road has been washed out at least twice, notwithstanding the breakers.

Example No. 4.—Same road as No. 3.

Original shape of ditch, flat V.
Width of roadway, 24 feet.
Sand-clay surface.
Average width drained by side ditch, including slope, 25 feet.

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Character of soil, mixture of light clay and fine sand.
Slope of ditch (grade), 6 per cent.
Length from summit to where erosion begins, 150 feet.
Below 200 feet it has been necessary to employ breakers, and below 400 feet the breakers have been washed out on several occasions and the ditch has become dangerous to traffic.

Example No. 5.—Same road and same conditions as No. 4, except width drained by side ditch, 13 feet:
Slope of ditch (grade), 1½ per cent.
Length, 600 feet, no erosion.

Example No. 6.—Washington-Baltimore road:
Age of road, 5 years.
Original shape of ditch, wide flat V.
Width of roadway, 27 feet.
16-foot bituminous macadam surface.
Average width drained by side ditch, 16 feet.
Character of soil, sandy clay with considerable gravel.
Slope of ditch (grade), 4 per cent.
Total length of ditch, 900 feet.
Below 800-foot point the ditch has eroded slightly, but maintenance is very light.

Example No. 7.—Washington-Atlanta highway in North Carolina:
Age of road, over 5 years.
Original shape of ditch, irregular but approximates the cross section shown in figure 1, with average bottom width of about 1 foot.
Width of roadway, 24 feet.
Earth road.
Average width drained by side ditch, 18 feet.
Character of soil, clay loam.
Slope of ditch (grade), 2½ per cent.
Length from summit to where erosion begins, 1,000 feet.
Water turned off at 1,100 feet.

Example No. 8.—Same road and same conditions as No. 7, except slope of ditch, 4 per cent:
Length from summit to where erosion begins, 500 feet.
Ditch becomes dangerous to traffic below 600 feet.

Example No. 9.—Same road and same conditions as No. 8, except soil is a very stiff clay and slope of ditch is 7½ per cent:
Length from summit to where erosion begins, 500 feet.
Difficult to maintain ditch below 600 feet; water turned off at about 700 feet.

GUTTERS.

Where the grade of a road is so steep that the ordinary earth side ditches can not be maintained satisfactorily at a reasonable cost, or where earth side ditches would be unsanitary or appear unsightly, it is customary to provide paved gutters for removing the surface water. The point at which it is economical to change from earth side ditches to paved gutters on account of the steepness of the grade depends on the character of the soil and the amount of water to be

carried. The influence of these factors has been discussed under the heading "Side ditches."

The proper type of gutter to employ depends on a number of considerations. Due attention should be paid in its design to having it of adequate size and properly correlated with the other parts of the surface drainage. If a ditch on a steep grade be replaced at some point by a paved gutter, the latter should of course be designed in harmony with the ditch it replaces. If a paved gutter receives a heavy discharge from side roads or elsewhere, the necessary changes should be made to prevent flooding. Often the distance of the gutter from the surface affects its design and type. A gutter paved simply to prevent erosion, and situated perhaps 10 feet from the edge of the surface, does not require the bearing strength of a gutter immediately adjacent to the surface and used often as an effective part of the traveled way. The surfacing material itself sometimes affects the gutter design, inasmuch as principles of harmony and uniformity of surface must be considered; and occasionally proposed methods of construction of the wearing surface affect the design of the gutter. All of these details must be considered, as well as the general ones of available materials and economic cost.

Gutters may be constructed of Portland cement concrete, brick, cobble stones, angular fragments of stone, or other similar material. In some cases they are formed simply by constructing a curb along the edge of the road surface, as is done sometimes in city pavement construction. This method can be employed only where the road surface is made of material capable of withstanding the eroding action of water and where it is not important that the earth shoulders be kept open to vehicle traffic.

Gutters are made from 2 feet to 6 feet wide and from 3 inches to 10 inches deep, depending to a great degree on the type of design, and the size is governed by the same considerations as govern the size of earth-side ditches. That is, they should have a cross section sufficient to drain the road without danger of overflow, and, in order to determine this cross section, it is necessary to consider the area to be drained, the maximum rate of fainfall and run-off, and the character and slope of the gutter. Tables 2 and 3 give the capacity of gutters having various shapes, slopes, and cross-sectional dimensions. The values given in these tables were computed for cobble and concrete, respectively, but may be used in designing other type of gutters, provided the relative surface roughness of each type is properly considered. In Tables 6 and 7 will be found velocity-quantity figures for an alternative design for concrete gutters. In making the computations the cobble gutters were assumed to have their characteristic rough finish, and the concrete gutters a smooth,

even surface. In designing gutters it is well to bear in mind the following points:

1. It is not usually necessary to extend a gutter entirely to the top of a grade, because, as examples cited indicate, there usually is not water enough flowing in the upper part of the side ditch to cause erosion.

2. It is not usually economical to vary the size of the gutters on long grades so that they will have only the required capacity at all points; but changes may and should be made if any considerable change occurs in the required capacity.

3. All gutters should be sufficiently strong to withstand the impact caused by an occasional vehicle being driven into them, but unless they are capable of withstanding constant vehicular traffic they should be designed so as to discourage the practice of driving into them.

4. The grade of gutters should be made as uniform as practicable in order to prevent them from becoming partially filled by sedimentation, and should not be less than 1 in 200.

Brief directions for constructing the most common types of gutters follow:

COBBLE GUTTERS.

Cobble gutters are ones constructed of rounded water-worn stones, ranging in size from 4 to 8 inches in their longest dimension. The stones should be sound, durable, and fairly uniform in shape. The construction of the gutter should proceed about as follows:

First, excavate a trench to receive the gutter. The trench should have a width equal to the outside dimensions of the gutter and should be excavated to a depth of about 12 or 14 inches below the proposed grade of the gutter.

Second, spread sufficient broken stone or gravel in the bottom of the trench to give a depth of about 6 inches when thoroughly compacted. The broken stone or gravel should be of the kind ordinarily specified for macadam or gravel roads and should be compacted thoroughly with hand rammers.

Third, spread a layer of bedding sand over the foundation to such a depth that when the cobblestones are bedded into the sand and rammed thoroughly, they will form a gutter true to grade, line, and cross section. For cobblestones of fairly uniform size a depth of about 2 inches usually is sufficient for the sand bedding.

Fourth, place the cobblestones. In doing this the larger and more nearly perfect stones should be selected and placed true to line and grade in the edges and in the row which forms the lowest part of the gutter. All stones should be laid with their long diameter lengthwise of the gutter and should fit snugly one against the other. Each stone should be rammed until it no longer yields under the rammer, and any irregularities which may develop should be corrected by resetting the affected portions. While the ramming is in progress, sufficient coarse sand should be spread over the surface to keep the joints between the stones well filled. When the ramming is complete, the surface of the gutter should be uniformly true to line and grade. Wherever changes in the dimensions of the gutter are necessary, they should be made gradually, and not by abrupt off-sets.

Fifth, where the grade of a cobble gutter exceeds about 5 per cent, and the volume of water it must carry is at all considerable, the interstices between the stones should be filled with Portland cement grout instead of sand, as above described. A suitable grout for this purpose may be made by mixing

together 1 part cement, 2 parts sand, and sufficient water to give the grout a consistency about equal to that of ordinary cream. When the joints are grouted, the bedding sand should not extend above the center of any stone; because, if it does, the grout is very likely to crack and spall out.

This type of construction will give a gutter practically as strong as the road surface and may consequently be used in juxtaposition to

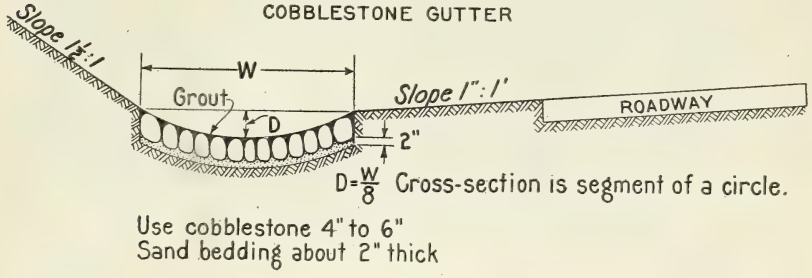


FIG. 4.

it. If there is little probability that traffic will use a gutter, naturally such heavy construction is not necessary. There are cases when adequate gutters may be built on a thin course of cinders with a sand bedding course. If the soil be not noticeably poor, 4 inches of cinders or gravel will be adequate. In some cases, on unusually favorable soils, such as sands or sandy loams, it may be possible to build immediately on the soil in place or with nothing more than the sand bedding course added.

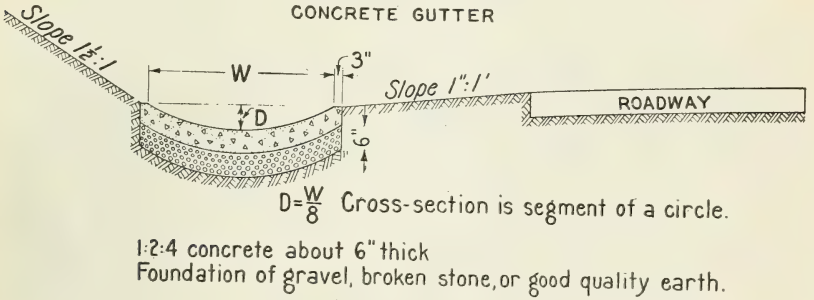


FIG. 5.

Figure 4 shows a typical cross section for a cobble gutter, and Plate I is a photograph showing a completed gutter which was constructed in accordance with the foregoing directions and which is now giving satisfactory service. Sand was used for filling the joints in this gutter.

CONCRETE GUTTERS.

There are two types of concrete gutters in general use. One has a curved cross section, as shown in figure 5, and the other is essen-

tially a sloping shoulder with a raised curb at the outer edge, as in figure 6. The first is adapted for use where the road follows the natural surface of the ground closely, and there is no especial difficulty in securing the necessary width for road and gutters. Where the road is located in a deep cut, on the other hand, or where for any reason it is especially desirable to utilize the gutter as a part of the road surface, the second type should be employed. The method of construction is practically the same for both types and may be described briefly as follows:

First, the foundation should consist of broken stone, gravel, or a good quality of earth brought to the required shape and thoroughly compacted by rolling or tamping, as in the case of cobble gutters. The location and probable demands on the strength of the structure determine the expense justifiable in any case. Where earth is used as a foundation in cold climates, great care should be exercised to see that it is well drained, as otherwise freezing may cause the gutter to heave.

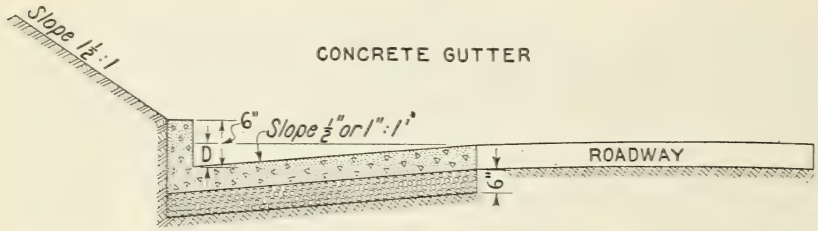


FIG. 6.

Second, the gutter paving should consist of concrete mixed in the proportions 1 part of Portland cement to 1½ parts of clean coarse sand and 3 parts of crushed stone or gravel that will pass a 1½-inch screen and be retained on a ¼-inch mesh screen. If the paving is merely to prevent erosion and will take no traffic a 1-2-4 mix may be used. The concrete should be mixed to a rather dry consistency so that it will hold its shape in the gutter, and should be thoroughly tamped until all the voids are filled and mortar flushes to the surface. The surface then should be brought to a smooth, uniform finish by striking off with a template shaped to conform with the cross section of the gutter and floating with a wooden float. In the case of the curb gutter, the mortar should be worked down into the face of the curb with a spade.

Fourth, joints extending entirely through the gutter should be constructed at intervals of about 20 or 30 feet. The joints may be made conveniently by means of bituminous felt strips placed in the gutter during construction. The bituminous felt, which should be about ¼ inch thick, is held in place with a template until the concrete is against it.

Fifth, after the gutter is finished as above described, it should be protected from the drying action of the sun and atmosphere for about two weeks. This is necessary to prevent the concrete from developing excessive shrinkage, cracking, and being damaged otherwise from too rapid drying out. One of the most satisfactory ways of protecting the concrete is to cover it with canvas as soon

after it is placed as can be done without marring the surface, and keeping the canvas wet constantly. After about 24 hours the canvas may be removed and replaced with an earth covering about 2 inches thick. This earth covering should be kept moist by periodic sprinkling during the two weeks it remains on the pavement.

BRICK GUTTERS.

Brick gutters may be constructed in a manner similar to that described for cobble gutters, or they may be made as a part of the road surface, as in the case of the second type of concrete gutter described. They are used seldom on country roads except in connection with brick pavements, and need not be especially discussed here, as the method of constructing the gutters should not be essentially different from that prescribed for the pavement.

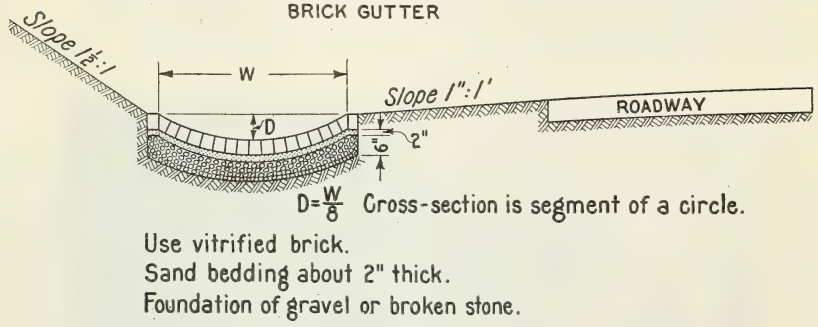


FIG. 7.

COST OF GUTTERS.

The cost of constructing gutters varies to a very great extent and depends principally on the design of the gutter, the construction methods employed, and the availability of materials. The amount of work to be done may also, of course, have an important influence on the unit cost, because this feature determines, in a great measure, the manner in which a force of laborers should be organized for carrying on the work. If the special conditions affecting any particular case are properly considered the following data should afford a fairly reliable basis for preparing cost estimates for the three types of gutters discussed above.

First, consider a cobble gutter of the cross section shown in figure 4, the foundation to be of crushed stone or gravel and the joints to be filled with Portland-cement grout.

Materials required for 100 linear feet:

Foundation, 0.20 cubic yard crushed stone or gravel.

Sand bedding, 0.07 cubic yard sand.

Cobble paving, 0.15 to 0.20 cubic yard cobblestones.

Grout, 0 05 to 0.08 barrel of cement, 0.20 to 0.30 cubic foot of sand.

Second, consider a concrete gutter of the circular section shown in figure 5,

the concrete to be mixed in the proportion 1 part cement, 2 parts sand, 4 parts crushed stone or gravel; the gutter to be given a 1 : 2 mortar finish and to have a total depth of 6 inches.

Materials required per square yard of gutter:

Portland cement, 0.25 to 0.30 barrel.

Sand, 0.070 to 0.080 cubic yard.

Crushed stone or gravel, 0.14 to 0.15 cubic yard.

Tar paper or bituminous felt, ——.

(If the mortar surface is omitted, this would reduce the cost about 5 or 6 cents per square yard.)

Third, consider a brick gutter, figure 7, similar in cross section to the cobble gutter, the foundation to be of crushed stone or gravel, the paving to consist of vitrified paving brick laid on edge with the long dimensions in the longitudinal direction and the joints to be filled with Portland-cement grout.

Materials required per square yard of gutter:

Foundation, 0.20 cubic yard crushed stone or gravel.

Sand bedding, 0.055 cubic yard sand.

Paving, 40 paving brick.

Grout, 0.03 to 0.04 661 cement, 0.014 to 0.16 cubic feet of sand.

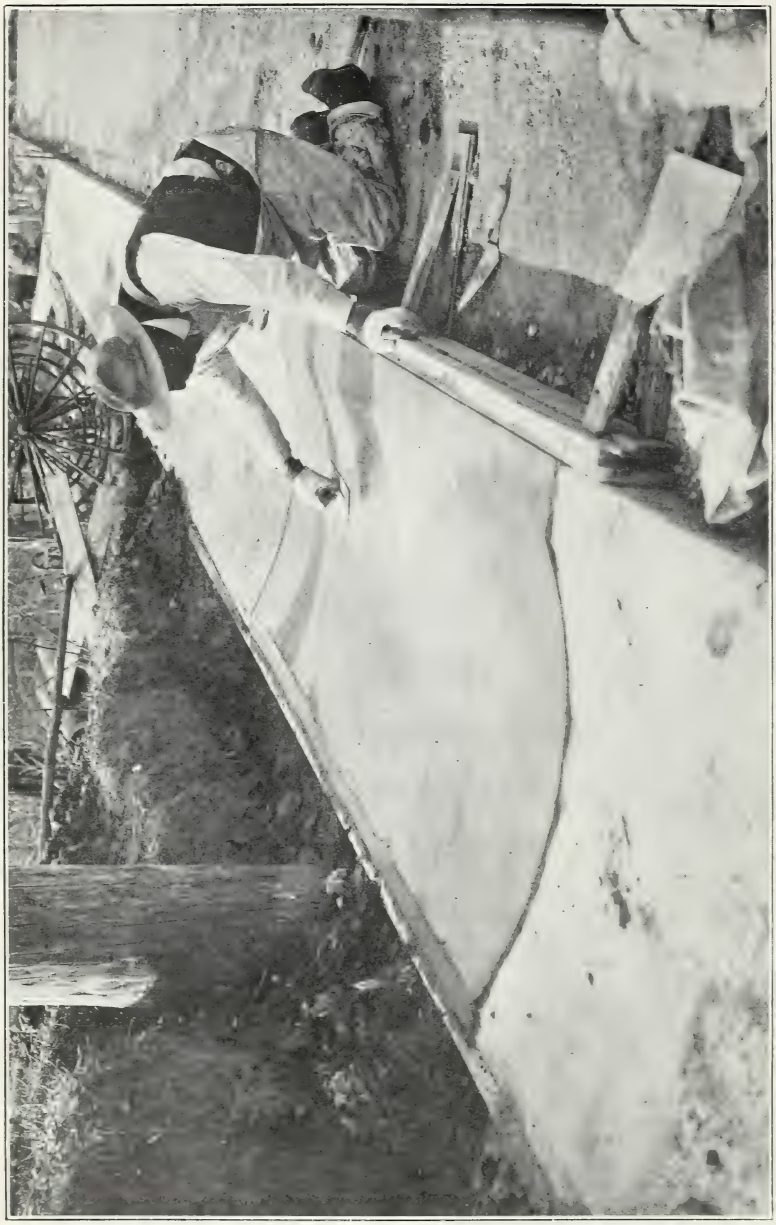
DROP INLETS AND CATCH BASINS.

Drop inlets and catch basins are used to conduct water from side ditches or gutters into underground drains or culverts. On country roads they are used most frequently on side-hill locations where the water collecting in the upper side ditch or gutter can be removed from the road at intervals by means of a culvert across to the lower side. Where the development contiguous to the road is suburban in character they may be required by a variety of conditions. Drop inlets usually are sufficient for this purpose and catch basins seldom are used in country-road work, except where it is especially desirable to prevent the silt and other foreign material carried by the water from getting into the underground drainage structure.

Where catch basins or drop inlets are to be used, their location and design are of especial importance. It is almost as common a fault, however, to omit them as to introduce them improperly into the drainage system. As indicated above, they are used to relieve the upper ditch or gutter and therefore have a close relation to the capacity of such gutter and its tendency to erode. Rightly placed, they afford a means of controlling the amount of water delivered by successive sections of gutter to the sections immediately adjacent, and enabling a gutter of uniform cross section to be designed for long slopes. In handling hillside drainage it is good practice to clear the gutters at the crest of the grade. If water has been brought across a flat to the top of a hill it is likely that in heavy rains the hillside ditches will be overcharged unless relieved at frequent intervals. Culverts placed under the road to provide such relief should have some form of intake that will direct water into them. The drop inlet may be used for

FIG. 1.—WOODEN WATER BREAKERS SET IN DITCH TO PREVENT SCOUR.

FIG. 2.—GROUTED COBBLE GUTTER.



FINISHING CONCRETE GUTTER.

FIG. 1.—BRICK GUTTER OF SATISFACTORY DESIGN FOR SMALL FLOW.

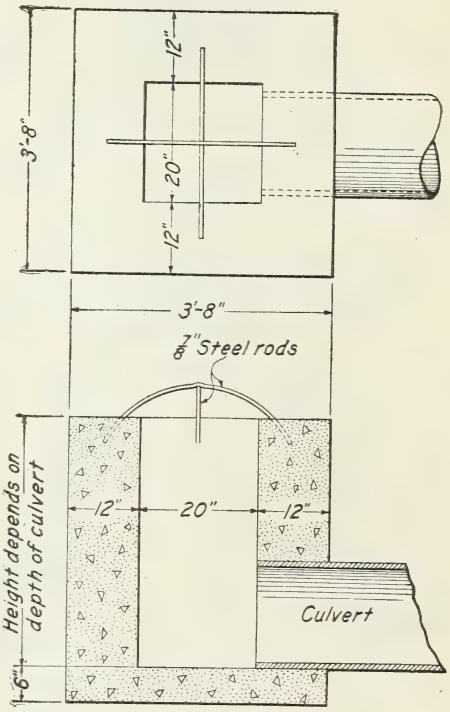
FIG. 2.—DROP INLET OPENING WITH CAST-IRON GRATING.

FIG. 1.—CONCRETE GUTTER AND CURB OF DESIGN SHOWN IN FIG. 6.

FIG. 2.—FRENCH TYPE OF SUBDRAIN WITH BELL AND SPIGOT PIPE AND STONE BACK FILLING.

this purpose, and the culverts and inlets should be placed at such intervals as to prevent the ditch from eroding or overflowing. The distance apart depends on the capacity of the gutter as designed. If the gutter be large enough it may be possible to use few cross drains or culverts and space them at intervals of several hundred feet. Under other conditions they may be required at intervals of as little as 50 to 100 feet.

The design should provide an inlet that will carry all that the cross drain will, and usually there is little difficulty in securing this condition. It is not essential that the inlet and cross drain be designed to clear the gutter if this be continuous, and the inlet entrance consequently may be a flat grating or opening designed to admit only a part of the flow. Usually, however, if the expense of inlets is incurred it is best to clear the ditches at each point, and the capacity of the culvert and inlet should be calculated accordingly. It is also good practice to make the gutter continuous, so that if the inlet becomes partly or temporarily clogged the water may continue along the gutter. On very steep grades it is well to design the inlet opening with a baffle on the lower side, so that all water flowing in the gutter to that point will be taken. In the baffle there should be a depression along the upper edge to provide relief in case the inlet becomes interrupted.



CONCRETE DROP INLET
Scale 3/4" = 1'-0"

FIG. 8.

Owing to the difficulty sometimes had in clearing such culverts and inlets of obstructions it is well to give careful consideration to the probable conditions under which they will operate. If they are frequently under a head the inlet will run full but little difficulty will be experienced in keeping the culvert clear even at a very low slope; but if the prevailing storms are light and only a small flow occurs ordinarily in the culvert the pipe should be given sufficient

fall to clear. One-quarter inch to the foot, or about 1 in 50, will be sufficient under all usual conditions. Of course the pipe should be designed according to the proposed slope. Whatever specification is used for ordinary pipe culverts, cementing the joints under no circumstances should be omitted when drop inlets or catch basins are used, on account of the possibility of operation under head.

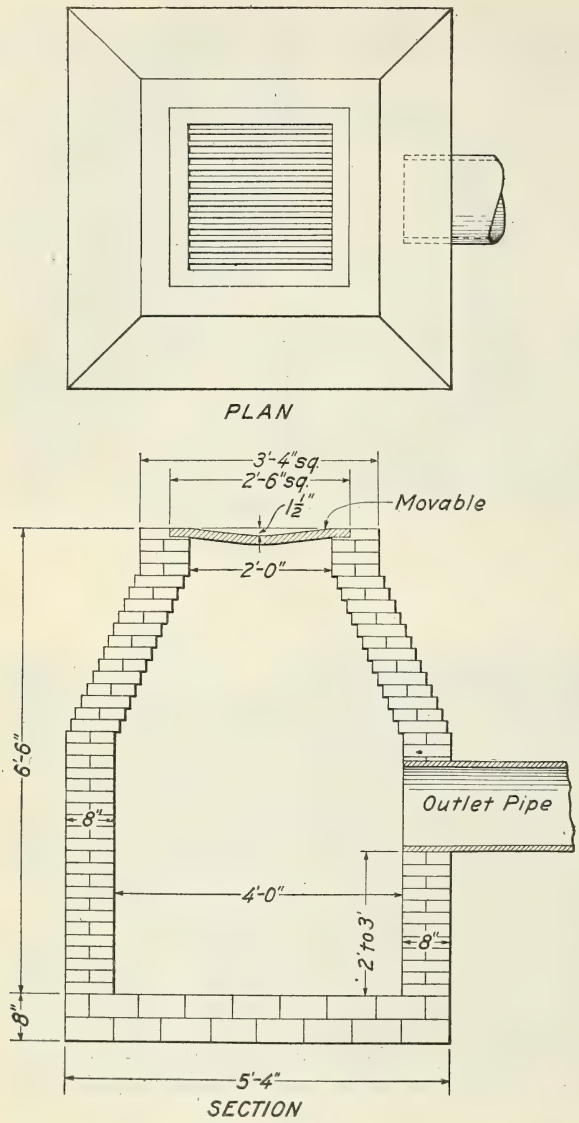


FIG. 9.

The materials ordinarily used in constructing drop inlets and catch basins are Portland cement concrete, brick, or stone. Figure 8 shows a design for a drop inlet constructed of concrete and figure 9 a catch basin constructed of brick. The only essential difference between the catch basin and the drop inlet is in the space below the end of the culvert pipe which is provided to collect sediment. Drop inlets usually are somewhat smaller than catch basins, however, because the latter always must be large enough to make cleaning practicable, and the former usually are designed to provide the necessary capacity for drainage only. Figure 10 shows a U-shaped head wall sometimes used for side-hill culverts

instead of the drop inlet and catch basin shown in figures 8 and 9. The dimensions shown in the figures are considered minimum for good practice, and it may be necessary to increase them where the volume of water to be cared for is large.

The photograph in Plate III shows a cast-iron grating suitable for covering either a catch basin of the design shown in figure 9 or a drop inlet of similar design. Where these structures are sufficiently far removed from the traveled way to obviate danger to traffic the cover design in figure 8 may be used. The practice of

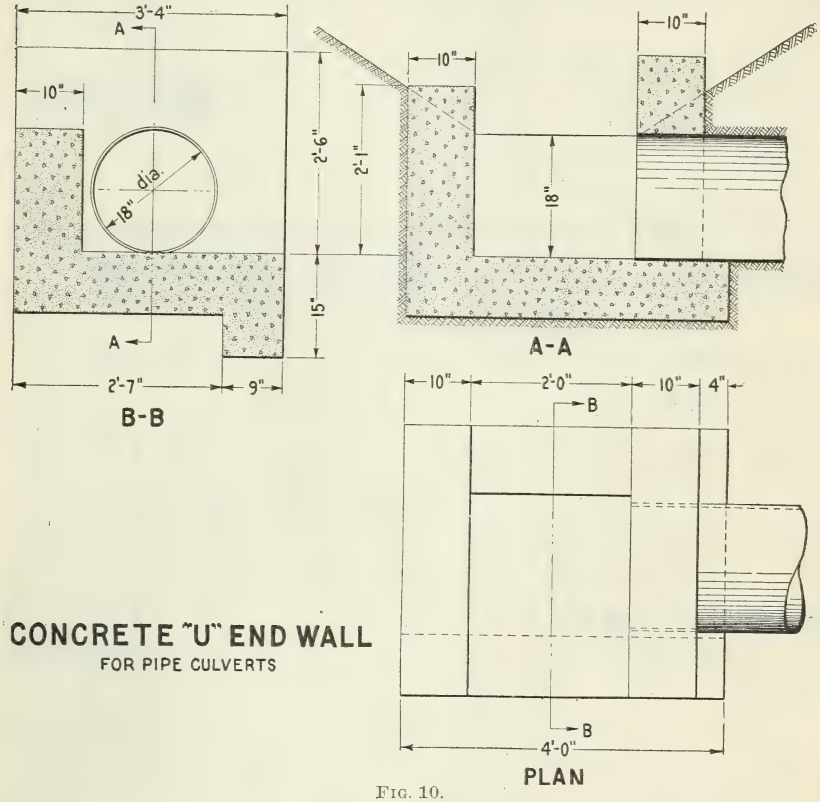


FIG. 10.

leaving the tops open always is objectionable on account of danger to animals, and also because the opening becomes obstructed with sticks, leaves, etc.

COSTS.

Such structures as are shown in figures 8, 9, and 10 usually may be constructed of 1:2:4 concrete at a cost of from $12 to $18 per cubic yard, including all form work. The labor cost per cubic yard should seldom exceed about $10.

The cost of suitable cast-iron covers, where standard designs are employed, averages about 2½ cents per pound in place.

The cost of stone masonry for such structures varies from about $6 to about $12 per cubic yard, according to the amount of difficulty experienced in obtaining the stone.

SUBDRAINAGE.

In addition to the side ditches, gutters, etc., required for draining storm water away from the surface of a road, it frequently is neces-

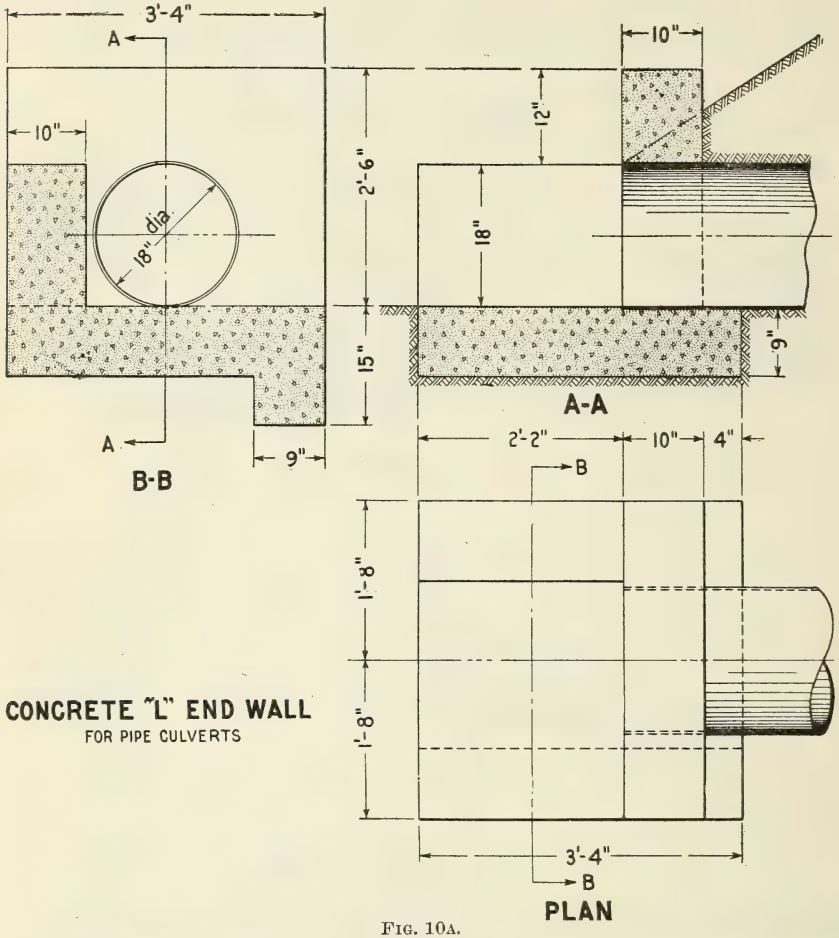


FIG. 10A.

sary to provide a system of subdrainage to lower the surface of the ground water under the road. The elevation of the ground-water surface depends on the capillary power of the soil and the hydrostatic pressure to which the ground water is subjected, and under some combinations of soil and topography this elevation may be such as to destroy the stability of the roadbed unless subdrainage be provided. The common methods of providing subdrainage are, first, by open ditches; second, by ditches filled with broken stone or gravel; third,

by tile drains; and fourth, by V-drain foundations. Each of these methods will be discussed briefly.

OPEN DITCHES.

Open ditches have been used frequently in some of the Southern States for subdraining roads through low flat sections. Ordinarily only one ditch is used, and it is located a few feet outside of and parallel to the road. This ditch usually is made about 2 feet wide and 3 or 4 feet deep, with the banks vertical. The material excavated from the ditch is used to build up the roadbed, and the surface water from the side ditches is turned into the deep ditch at convenient intervals.

The use of such ditches should be decided upon with care. There are ditches in the South, within the coastal plain, where sand clays and indurated clays occur a few inches underground, that have stood with vertical sides since the middle of the last century. They have been cleaned repeatedly and no doubt have become somewhat enlarged, but considering the cost of maintenance and the service given they have been entirely satisfactory. In other soils of a gravelly nature, however, the sides of such ditches would not stand, and the cost of keeping them clean would be excessive.

The open ditch is not to be selected for use in all locations. At best, when used near roads, it is dangerous and often unsightly. To keep it far enough from the traveled way to reduce danger to passing traffic to a minimum, it has to be deepened or lose somewhat its effectiveness. In general, this method gives fairly satisfactory results for a short time, provided the ditch be dug to a uniform grade and supplied with a suitable outlet. But a ditch of this kind, under ordinary conditions, soon will become obstructed by the banks breaking away and by the growth of vegetation, and is very seldom economical in the long run. There are few cases where a tile drain would not perform the work equally as well as an open ditch, and a tile drain possesses the advantage that when once completed, it will last indefinitely with practically no attention.

If open ditches are used for subdrainage they should be located carefully and constructed so they will perform their intended function. It is almost impossible to locate such a ditch that will not act somewhat as a surface drain, and in this event the possibilities must be considered. Frequently the ditches are designed to act in both capacities, but this practice is distinctly faulty if the depth of ditch is increased thereby much over what would be required for surface drainage alone.

DITCHES FILLED WITH STONE.

Ditches filled with broken stone or gravel sometimes are used as a substitute for tile drains to be described later. These have been used

in all sections of the country and, when properly constructed, usually have proved satisfactory for a considerable period of time. When such ditches are used it is common practice to place one on each side of the road immediately under the ditches. They are excavated to a depth of from 2 to 3 feet with vertical sides, and usually are made about 18 inches wide at the top or just wide enough for a man to work in them conveniently. To be effective they must have a uniform grade and be carried to a suitable outlet.

While common practice in this regard is as cited, it is not the best. Unless great care is taken in grading the material with which the ditch is filled, there is a marked tendency in all heavy storms for the stone-filled trenches to flush full of water heavily laden with silt and become clogged. A much better design is to lay one ditch down the center of the road, sufficiently deep to lower the water table enough at each edge and to cover it with the surfacing material. In

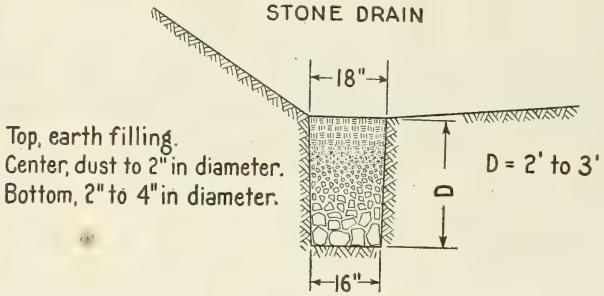


FIG. 11.

this way, the amount of storm water it accumulates by percolation is a minimum and it gathers no silt.

The stone or gravel used for filling these ditches should preferably be of a uniform size so that the percentage of voids will be high. A material consisting of rather large particles also is to be preferred because the individuals voids in such material are large and are not so easily filled by deposits of silt.

If the subdrainage ditches are placed under the side ditches, the stone or gravel fill should be graded finer for about 6 to 10 inches near the surface, until the top 2 or 3 inches are sand, over which the natural soil and silt will tend to form a covering and so retard the filling and clogging of the lower stone. This grading of material is entirely unnecessary if the ditch is located under the surfacing. Figure 11 shows a typical cross section for a ditch of this kind. In the cross section large stones of a uniform size are shown in the lower part of the ditch and finer material in the upper part. This is a very effective arrangement, as the fine material near the top prevents silt from being carried down by the surface water and deposited in the interstices between the stone in the bottom layer.

TILE DRAINS.

Tile drains are, in general, much superior to either open ditches or ditches filled with stone for subdraining roads, and though generally more expensive than either open or stone drains, generally can be constructed at comparatively small cost. These drains, sometimes called French drains, are designed as shown in figure 11A. The depth of stone or gravel fill placed around and above the pipe varies according to the soil and ground water conditions. In some instances the stone fill is carried to the surface, in others it is omitted entirely. If a complete interception of underground flow is required in highly stratified material, it is best to fill the trench entirely with stone or gravel, but this is rarely necessary and when unnecessary is a waste of material. In any case, precautions should be taken to prevent

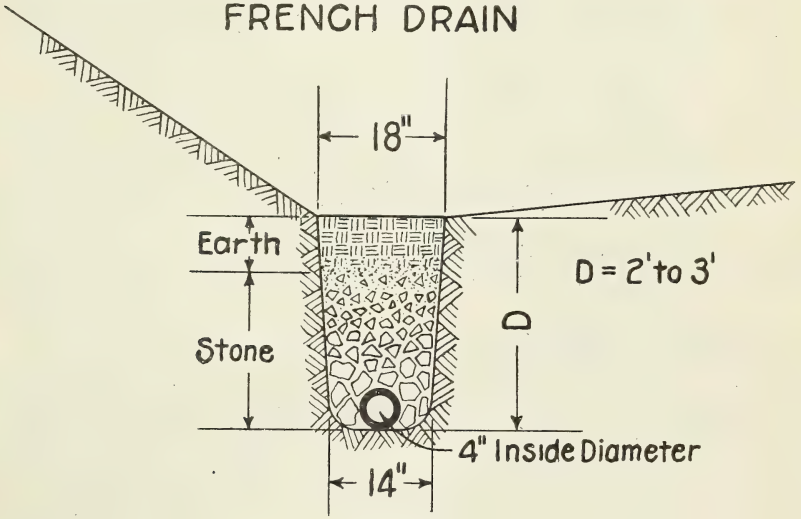


FIG. 11A.

silt from entering the pipe or clogging the stone fill. It usually is effective to lay tarred paper strips or pieces of broken tile over and around the joints when the trench is to be back filled with earth. If stone or gravel fill is used the same arrangement of sizes should prevail as for stone drain already described, care being taken to have an unbroken layer of sand on top of the finest stone.

Practice varies with regard to location of such drains. Ordinarily, one line of tile laid immediately under one of the side ditches and at a depth of 3 or 4 feet below the center of the road is sufficient, but where the soil is unusually retentive, two lines may be necessary. In some cases a single line of tile laid along the center of the road has proved satisfactory in retentive soils.

Where, on account of the design of the side ditches, or for other reasons, it is not desirable to place a tile drain under the ditch or

gutter, it may be located in the shoulder under the edge of the surfacing. The principal objections to locating the drain under the center of the road are that it is very difficult to back fill the trench in which the tile is laid so that no settlement will take place, and in case of injury to the tile repairs are hard to make and always interfere more or less with traffic. Where a center location is selected, corresponding care to insure proper alignment and grade and to prevent silting of the stone or pipe line should be taken. Where the road is located on a side hill it is usually satisfactorily subdrained by one line of tile placed on the up-hill side so as to intercept the flow of the ground water.

SIZE OF TILE.

The proper size of tile for any particular location depends upon the rate of the run-off and the slope of the tile. Where the topography is flat and no surface water is allowed to enter the tile directly it may be assumed safely that the maximum amount of water drained off in 24 hours would cover the area drained by the tile to a depth of about one-fourth inch, or that the maximum run-off would be about 35 cubic feet per hour for each acre drained. Where the topography is more or less broken or where springs empty into the tile, this maximum run-off may be increased very materially, and the probable influence of such factors as these always should be considered in fixing the size of the tile.

In order to determine the area a given tile will drain it is necessary to know how far out on each side of the tile the level of the ground water will be affected. In loose sandy soils this distance may be assumed to be about 100 feet, while in stiff clays that tend to retain water the level of the ground water may be practically unaffected at a distance out of only 20 or 25 feet. For most soils that require subdrainage it probably is safe to assume that the area drained on each side of the tile is from 30 to 50 feet wide. These distances are essentially affected by the depth at which the tile is laid. To develop the highest service in sandy soils the depth should be from 3 to 4 feet, while in stiff clays the depth should not exceed 2½ to 3 feet. Where deep freezing is likely to occur and heaving or disalignment of the tile can be expected, it should be laid deeper, of course, and the number of lines increased if necessary to reduce the ground water peak between them.

Table 4 shows the sizes of tile required to carry various amounts of water. An examination of this table will show that rarely under conditions ordinarily encountered in road work need the diameter of the tile be greater than 6 inches, and that for most conditions a diameter of 4 inches is sufficient. No matter how small may be the amount of

water to be drained off, the diameter of the tile never should be less than 4 inches, because experience has shown that tile having a smaller diameter is very liable to become obstructed by sediment. The larger diameters given in the table generally are used only where it is necessary to admit more or less surface water directly into the tile, or to provide for some unusual flow from springs.

CLAY TILE.

Clay tile of the diameters shown in Table 4 is manufactured in almost every section of the United States. The ordinary farm tile, without the bell joints, is the kind most generally used for subdraining roads, and is generally satisfactory when laid at the side of a road where it will not be subjected to heavy loads. The tile may be either round or hexagonal in cross section and should be straight longitudinally, well burned, and free from cracks. The nominal section lengths are 12 inches for the smaller sizes and 2 feet or 2 feet 6 inches for the larger sizes. In practice, the lengths generally are made slightly in excess of the nominal to allow for a small amount of breakage. The ends always should be cut square in manufacturing so that successive sections may fit together snugly, but seldom does this condition exist. To make a good fit it is necessary at the time of laying to turn the tile over until the ends make the snuggest joint. If the cost of bell tile is not prohibitive they may be used to advantage in place of butt-joint tile.

Table 8 gives the average weight and the average number of feet in a carload for the various diameters of field tile. The costs at the factory are subject to more or less variation, and freight charges on tile have been relatively high, so that the costs of pipe delivered at railroad points some distance from the factory are so constantly variable that tabular figures are of little value. Where more than one size of tile is shipped at the same time, the amount in a carload may be increased and the freight per ton decreased by nesting the different sizes.

TABLE 8.—*Cost and weight of drain tile.*

Inside diameter.	Average cost per 1,000 feet f. o. b. factory.	Average weight per foot.	Average number of feet in a carload.	Inside diameter.	Average cost per 1,000 feet f. o. b. factory.	Average weight per foot	Average number of feet in a carload.
Inches.		*Pounds.*		*Inches.*		*Pounds.*	
4	$15.00	8	6,500	12	$95.00	36	1,000
5	22.50	10	5,000	15	140.00	50	700
6	27.50	12	4,000	18	245.00	72	400
8	47.00	18	2.500	24	370.00	115	300
10	67.00	28	1,600				

CONCRETE TILE.

Concrete tile is made from Portland cement and sand or fine gravel and may be substituted for clay tile wherever conditions are such as to make the use of concrete economical. The only exception to this rule is that where the water a tile is intended to carry contains any considerable quantity of either alkali or acid clay is preferable to concrete, because concrete may be destroyed quickly by strong alkali or acid, while these materials do not affect clay tile seriously. Machines for manufacturing concrete tile may be purchased for from $40 to $100 and may be operated either by hand or by a suitable engine. Table 9 shows the size, weight, and quantities of materials required for concrete tile of various diameters, and the following list of suggestions are practically sufficient to serve as a guide in the manufacture of such tiles.

TABLE 9.—*Concrete tile.*

[Straight tile—concrete mixed in proportion 1:3.]

Diameter.	Thickness.	Weight per foot.	Material required per 100 feet.		Diameter.	Thickness.	Weight per foot.	Material required per 100 feet.	
			Cement.	Aggregate.				Cement.	Aggregate.
Inches.	*Inches.*	*Pounds.*	*Bbls.*	*Cu. yds.*	*Inches.*	*Inches.*	*Pounds.*	*Bbls.*	*Cu. yds.*
4	¾	10.6	0.67	0.30	9	1¼	38.6	2.44	1.09
5	¾	13.1	.83	.37	10	1¼	42.6	2.72	1.20
6	¾	15.3	.97	.43	11	1¼	46.5	2.96	1.31
7	⅞	21.3	1.36	.60	12	1¼	50.4	3.20	1.42
8	1⅛	31.2	1.98	.88					

1. Use a reputable brand of Portland cement known to conform with some standard specification, such as that of the United States Bureau of Standards, published in their bulletin No. 33.

2. The sand used as aggregate should be clean and graded in size from fine to coarse, with the coarse grains predominating. For the smaller sizes of pipe all the sand should pass a ¼-inch mesh screen, but for the larger sizes it is economical to have the aggregate consist partly of fine gravel that will pass a ½-inch mesh screen. The proportion of gravel to sand should not be greater than 2:1.

3. The proportion of cement to aggregate should be about 1:3, but if the sand be inferior in any respect the amount of cement should be increased.

4. In making the tile, the concrete should be tamped into the forms so that no open or porous spaces are left, and the consistency of the concrete should be such that this can be done with comparative ease.

5. After the tile is finished and the forms removed it should be protected from the drying action of the sun and air and kept wet by sprinkling for at least seven days. Then the tile should for about 60 days be left in a protected place before it is used.

6. The cost of concrete tile depends on the cost of the materials of which it is composed and the cost and efficiency of labor. These are so variable in different localities that figures of general value can not be given. In general, the cost of concrete tile probably would average slightly greater for the smaller sizes and slightly less for the larger sizes than that of clay tile.

LAYING THE TILE.

In laying the tile work should begin at the lower end of the drain and proceed up hill when bell tile is used, and, in general, the work of excavating, laying and back filling should follow this rule, so that the various steps may be taken and the ditch drained at all times. To insure that the tile is laid true to grade, it is necessary to employ grade stakes, which are usually set by means of an engineer's level. These stakes should be spaced about 50 feet apart and offset sufficiently far from the line of the drain not to be disturbed while the ditch is being excavated. The excavation ordinarily is carried down to within a few inches of grade with plows, picks, shovels, etc., and the bottom of the trench is finished with a tile scoop. In handling the scoop great care must be exercised in order to bring the bottom of the ditch to a uniform grade and at the same time scoop out a properly shaped trench to receive the tile.

The tile should be laid as the ditch is completed, and each section should be turned until the ends fit together closely. Small openings at the joints, due to slight unevenness of the ends, are permissible, provided they are made to come in the bottom of the tile, but any opening more than about $\frac{1}{4}$-inch wide should be covered with a piece of broken tile, cement mortar, or heavy tar paper. In the case of fine sandy soils, all joints should either be wrapped with cloth or tar paper. This is necessary in order to prevent sediment from being carried into the tile. Wherever two drains come together, the junction should be made preferably by means of T or Y branches, because, when it is attempted to cut straight sections of tile to fit an angle, one section is very likely to project into the other and cause more or less obstruction. In case it is necessary to use straight tile on curves the joints should be covered with pieces of broken tile. Curves in a tile drain always should be as gradual as the location will permit, and should be avoided if possible.

As soon as the tile is laid it should be covered carefully to a depth of 5 or 6 inches with loose earth to hold the different sections in

proper position and to prevent displacement of the pieces of tile used for covering the joints. The back filling then may be completed, when convenient, with plows and drag scrapers, and after the surface over the drain has finished settling, it may be smoothed to the required shape with a road grader or a split-log drag.

If the drains are laid in the center of the road the back fill should be rammed carefully and firmly just as soon as enough has been placed to protect the pipe from displacement and damage. The back filling then should continue in layers, each one being rammed to provide so far as possible against settlement.

Where tile drains are constructed through unusually retentive soil and it is desired to secure the maximum efficiency from them, the trench should be back filled with crushed stone or gravel for 6 or 8 inches around and above the pipe. The proper method of making a back fill of this kind is indicated in the typical specification on page 81.

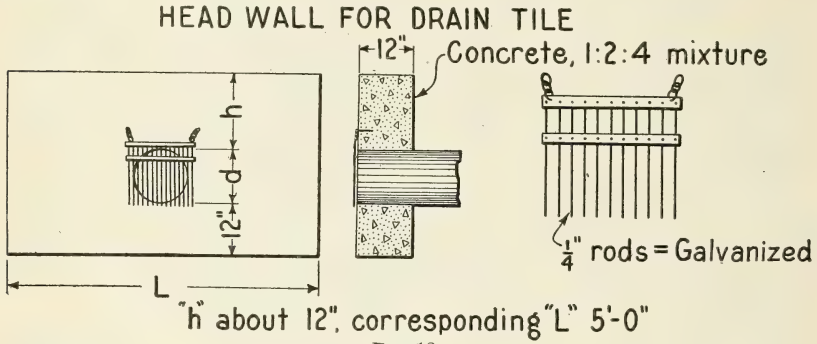


FIG. 12.

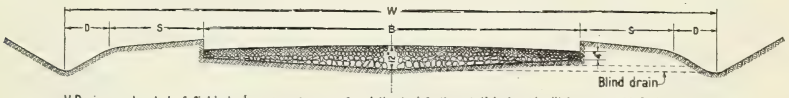
TILE-DRAIN OUTLETS.

Figure 12 shows an outlet for a tile drain protected by means of a head wall. The head wall prevents the end of the drain from being undermined and destroyed and also holds the earth in place at that point. The swinging screen over the end of the tile, which is shown in the figure, is intended to prevent rodents and other small animals from obstructing the tile with nests during dry seasons. In the past, outlets have not always been protected in this way and as a result trouble has been experienced frequently.

Satisfactory head walls may be constructed of stone, brick, or concrete. Wooden boards also have been used for this purpose, but are subject to the disadvantage that they must be replaced every few years, while the other materials are practically permanent. The screen over the end of the tile may be made of steel rods sharpened at their lower ends, and is suspended from the head wall by means of staples and links.

COST OF CONSTRUCTING TILE DRAINS.

The cost of laying tile drains, including necessary ditching and back filling, varies largely on account of variations in costs of material and labor, as already indicated. Where stone occurs in the ditch, or where any other condition makes excavation unusually difficult, the cost will be increased substantially. Where the soil is unusually soft, it is necessary sometimes to place boards in the bottom of the ditch to keep the tile from settling out of line, and in this case the cost of laying the tile, including the purchase of the boards, will be increased still further. In the rare cases where the conditions are such as to make it desirable that the ditch be entirely back filled with crushed stone or gravel so that the tile may do its work to the best advantage the cost of stone or gravel may be considerable. The additional cost of handling such cases would depend, of course, on the availability of the materials used in the back fill. In some cases the total cost, including all labor and material, has exceeded $50 per 100 feet, although $10 to $12 per 100 feet are commoner figures for ordinary tile drain.



V-Drain constructed of field stone or gravel where foundation is defective. Outlets to side ditches every 50 feet
Ditches to be of sufficient depth to drain V-drain

V-DRAIN

FIG. 13.

Suitable head walls and outlets for tile drains may be constructed at small cost. The design shown in figure 12 ordinarily can be built at a cost not to exceed $5 or $6. In some cases stone masonry may be employed at even a smaller cost.

V-DRAINS.

The V-drain shown in figure 13 and Plate V is especially adapted to localities where field stones can be obtained cheaply and in abundance. This type of drain is very effective when constructed properly and has the advantage that in addition to draining the subgrade of the road it provides an excellent foundation for the road surface. Its first cost is high when compared with the various types of side drains, but usually is much lower than the cost of side drains and Telford foundation combined. The latter comparison is, in general, the more reasonable one to make, because under favorable conditions a V-drain may serve to replace the combination of Telford foundation and side drains, and would be used seldom, if ever, where only drainage is needed to produce a stable foundation.

As shown in the cross-section drawing, figure 13, the V-drain is formed by excavating the subgrade of the road so that its cross section will have the shape of a flat V. This V-shaped trench is filled with field stone of all sizes from 6 to 8 inches in diameter down to pebbles only about 1 inch in diameter. The larger stones are placed in the center and lower part of the trench, while the smaller are placed on top and near the edges. It usually is necessary to spread the stone in two or more courses, so that it may be compacted to form a firm, unyielding foundation for the road surface. The compacting should be done with a power roller weighing about 10 tons, but should not be carried to such an extent as to fill the interstices between the stone in the lower part of the drain and thus prevent water from finding its way along the trench.

Some designs for V-drain, in order to save stone, require that the drain be carried out practically to 0 depth at the extreme edges, so that the stone or other road metal is practically without drainage at those points.

When V-drains of this design have been used in northern localities difficulty has been experienced with the edges of the road crust heaving in the spring. Probably this is due to the freezing of accumulated water near the edges of the drain. Such water will accumulate in the interstices as a result of shallow thaws that do not free the deeper areas of frost. The melted snow can not run off and fills the upper layers of the V-drain, especially near the edges, until the voids are too full to allow expansion on freezing. The result is that during succeeding freezes the edges of such drains will heave. The remedy is to increase the depth of V-drain at the edge and to provide drainage close to the surface through the shoulder so that such drains certainly will clear with the shallow thaws and permit water to flow freely from the V-drain. Experience indicates that the depth of V-drain, in addition to the surfacing material, should not be less than 4 inches at the edges, and that a depth of 6 or 8 inches is better.

Outlets for conducting water away from the V-drain should be provided at all low points in the grade. These outlets may consist of tile running from the lowest point of the V to a culvert or cross drain, or of ditches filled with the same kind of material as that composing the V-drain and running from the lowest point in the V to any lower point outside of the road where they may empty. In low flat sections, it frequently is difficult to provide suitable outlets for drains of any kind, and because V-drain foundations give the appearance of being very stable, whether or not outlets are provided, this feature sometimes is neglected in their construction. The result of such neglect is that water collects at low points in the grade and the roadbed at these points becomes excessively soft, and both roadbed and surface soon are badly out of shape.

COST OF V-DRAINS.

The most expensive feature of constructing a V-drain foundation is to collect and haul the field stones. The conditions affecting this part of the work seldom can be compared for different projects, even in a general way, and any cost data that might be given here would be more likely to prove misleading than otherwise. After the stones have been collected and hauled, the additional work required to put the foundation in shape usually is very slight, and its cost should not exceed a few cents per square yard. The cost of preparing the subgrade to receive the stones is discussed on page 51.

FOUNDATIONS.

In order to avoid confusion in the following discussion, the term foundation will be used to designate a specially constructed artificial base upon which the road surface or crust rests, and the term subgrade will be understood to mean that part of the roadbed, composed of natural earth or other similar material, which supports either the foundation, or in the absence of a foundation, the road crust. This distinction is purely arbitrary and is made simply for convenience.

The purposes of a foundation are, first, to aid in distributing the pressure due to wheel loads concentrated on the road surface so that the intensity of pressure on the subgrade will not exceed its safe unit bearing power, and second, to prevent, if possible, the crust of the road from being disturbed by the upward pressure of the subgrade due to the action of frost, ground water, or other disturbing influence. The relative extent to which these respective purposes should govern in designing a foundation depends on the character of the road crust and of the material composing the subgrade as well as on climatic conditions. For example, in the case of a pavement consisting of comparatively small blocks, such as vitrified brick, bonded to each other very slightly or not at all, an entire wheel load might be concentrated on only a few square inches of foundation, in which case it would be necessary for the foundation to take care of practically the entire distribution of the load. On the other hand, a monolithic pavement or a pavement in which the individual units are well bonded together might distribute the wheel loads sufficiently to obviate all necessity for further distribution by the foundation and if adequate drainage were provided and there were no danger of heaving of the subgrade, the foundation might be omitted entirely.

LOADS.

The heaviest vehicle that ordinarily has passed over a public highway heretofore is the 15-ton traction engine. Such engines usually are so designed that the rear axle carries about two-thirds of the total weight, which arrangement gives a concentrated pres-

sure on the road surface of about 5 tons under each rear wheel. The use of much heavier equipment is in sight, however, and unless some regulations be passed to prohibit it the occurrence of 10-ton or even heavier motor trucks on our local highways adjacent to large cities or between large centers that are only a few miles apart may become common.

Slight irregularities in the surface, due to faults in construction or developed by the wearing action of traffic, have the effect of producing impact under moving wheels and this action serves substantially to increase the pressure to be distributed by the road crust and foundation. On account of the impact which they produce swiftly moving motor trucks are sometimes more severe on road foundations than the heaviest traction engines, and if an improved road is to be subjected to any considerable volume of motor-truck traffic the impact feature should be given especial consideration when the road is designed.

In asuming the maximum wheel load for any particular road a reasonable allowance should be made for future increase. Since motor trucks have come into use there has been a constant tendency to increase both their rates of speed and the loads they carry, and it is quite probable that this tendency will continue. Furthermore, many roads not now subjected to motor-truck traffic will attract such traffic after they are improved, and this possibility always should be considered. Increase in the volume of traffic also may be an important factor, because a foundation ample to support an occasional heavy load might fail soon if the same load was often repeated.

DISTRIBUTION OF PRESSURE.

The manner in which pressure due to concentrated loads is distributed by the various materials used in road construction never has been fully investigated, and any assumptions regarding this point that may be made at present would be purely conjectural and of doubtful value. In the past engineers have made the questions of when a foundation should be employed and of how it should be designed wholly matters of judgment, and few, if any, rules have been formulated to aid even in making the judgment consistent for different conditions and materials. This lack of method is due directly to the absence of accurate knowledge concerning the cone of dispersion and pressure distribution under concentrated loads, and until further experimental data are obtained the design of road foundations necessarily must be based on rather uncertain empirical information so far as comparing the efficiency of different materials and methods of construction is concerned.

BEARING POWER OF SOILS.

On account of the uncertainty regarding the manner in which pressure due to concentrated loads on a road surface is distributed by means of the road crust and foundation, very exact knowledge concerning the bearing power of the soil composing the subgrade would be of small advantage in designing foundations. Such information would become of value only if a minimum bearing power were known, taking into consideration the effects of changing soil moisture. The most that can be done is to compare, in a general way, the soil conditions anticipated in the design with similar conditions on successful projects already completed and to consider known failures, the causes of which have been ascertained.

Such tests as have made for the purpose of determining the bearing powers of different soils have given more or less contradictory results, but all have shown a very wide variation for soils of practically the same character tested under identical circumstances. The following table gives averages deduced from available test results and may prove helpful in applying knowledge gained by experience in designing and constructing road foundations to similar work where the soil conditions differ from those already encountered:

TABLE 10.—*Safe bearing powers for different soils.*

Kind of soil.	Range of bearing power (pounds per square inch).	Kind of soil.	Range of bearing power (pounds per square inch).
Dry clay	50 to 80.	Moist loam	3 to 10.
Moist clay	6 to 50.	Dry gumbo	15 to 30.
Sand or gravel	25 to 85.	Wet gumbo	1 to 10.
Dry loam	10 to 20.	Marl	Same as clay.

This table indicates the extremely wide range of the available data and gives some idea of the value of judgment by the engineer in designing road foundations. It also demonstrates that figures in the matter are of little use with the very limited knowledge at our disposal.

Under the conditions ordinarily encountered in road work, the soil composing the subgrade is liable to become at least slightly moist, due to capillarity, even when the road surface is perfectly water-tight, and the effect of moisture in lowering the safe bearing power of the soil is an important consideration in determining whether a foundation is necessary and, if so, how it shall be designed.

The effect of capillarity can not be stated definitely, but that it has an influence on the condition and physical characteristics of the surface of the natural soil is certain. The amount of influence depends on meteorological conditions without and on various properties

within the soil, such as size and grading of soil particles, presence of organic matter, mineral salts, colloids, etc. Some of these properties produce opposite effects. The following table shows the height to which capillary water rises in certain soils in one day.

TABLE 11.—*Height to which capillary water rises.*

	Inches.
Light sandy soil	14
Gravelly soil	16
Decomposed granite (loam)	21
Heavy granite loam	16
Heavy clay loam	11
Heavy lava ash	16
Pure sand	9

In one day the capillary water moves upward about one-half its apparent final limit. In three days it moves about two-thirds its apparent final limit. In some soils the movement upward in the first two hours is as high as one-third of its movement for 30 days. In pure sand it rises in one-half hour approximately one-half as high as in one day and in one day about 70 per cent as high as in 12 days. The movement is more rapid at the start in light soils, and slows down rapidly. After three days the movement is exceedingly slow in pure sand. In heavy soils the movement is uniformly slower and more sustained. In light soils the per cent of water in the soil decreases rapidly with the height above the source, while in some heavy soils the moisture content is strikingly uniform at different depths. Horizontal capillarity occurs with much faster water movement and greater uniformity of moisture content. The speed and distance varies with different soils and ranges from 7 to 33 feet in the first 24 hours.[1]

The action of capillarity indicates that if water is to stand or flow along a road embankment for even a few hours, regard must be given to the height of the subgrade above the water line, and the lateral distance of the water course from the road crust or foundation. Assuming that the supply of free water will not endure more than one day at a time, it is apparent that a height in the subgrade of 18 inches above the water line will insure that the moisture content of the surface is not increased. Where the free water is present at a considerable distance to one side this height may be safely reduced. Shallow ditches a short distance from the center line tend, by horizontal capillarity, to increase the water content of the subgrade at a higher level than deep ditches similarly located. If the grade be through standing water or against a continuous source of free water so that the soil remains moist continuously, capillarity will lift the

[1] Capillary movement of soil moisture. Unpublished report of Riverside Exp., 1915–1917. W. W. McLaughlin.

water about four and one-half times higher than in dry soil.[1], and this fact must be considered in designing cross section and grade across swamps, marshes, or against irrigation or drainage ditches in which water is present for long periods. These conditions affect the design or cross section and the establishing of grade in places where the presence of free water is foreseen or where run-off is expected to be slow and considerable, if the full bearing power of the natural soil is to be developed. If, because of immediate local conditions, the design of cross section can not be made to meet the above requirements, then special drainage should be provided or additional bearing value provided through some suitable treatment.

The way in which the subgrade is prepared also, of course, affects its bearing power to a very considerable extent. In fact, the exercise of proper precautions in the matter of draining and compacting a roadbed sometimes may give the subgrade ample stability for directly supporting the road crust, where otherwise, if these features were neglected, an expensive foundation might be required in order to afford the same degree of stability.

INFLUENCE OF ROAD CRUST.

The considerations that should determine the form of support to be provided for any particular type of road crust are (1) whether it is practicable to make the crust sufficient to distribute wheel loads so that the safe bearing power of a well-prepared subgrade will not be exceeded, (2) the relative cost of increasing the depth of the crust so as to take care of the necessary distribution, where this is practicable, as compared to the cost of providing a suitable foundation of cheaper material, (3) the damage that would result to the road surface in case of slight settlement of the subgrade.

All of these considerations depend largely, of course, on the character or type of road crust to be employed. Where the crust is to be of Portland-cement concrete, or some similar type capable of distributing adequately the pressure due to concentrated loads the foundation evidently may be omitted, provided the crust is made sufficiently thick to take care of the distribution of load. In the case of sand-clay, gravel, and macadam, furthermore, slight disturbance of the subgrade might not result in any very serious injury to the surface, because the materials forming the crust which might be disturbed would be rebonded soon by the action of traffic. With any of the types mentioned, however, it might be more economical to construct a foundation of cheaper material than to provide the additional thickness of crust which otherwise would be required. This is

[1] Movement and distribution of moisture in soils. F. S. Harris and H. W. Turpin. Jour. Agr. Res., July 16, 1917, p. 117.

especially true of macadam and, as a consequence, both V-drain and Telford foundations have been employed frequently in connection with the macadam surface. It is less true of Portland-cement concrete only because its power of distributing pressure increases very rapidly with the depth and also may be greatly increased by properly arranged steel reinforcement which is usually cheaper to employ than any form of foundation.

Other types of road crust, such as blocks or setts, asphalt, and bituminous concrete, are intended only as wearing surfaces and in general must be supported on some form of artificial foundation. There are, of course, exceptional subgrade conditions where this is not true, as, for example, in the peninsular section of Florida, where the climate is mild and the soil consists essentially of sand which, when properly confined, has a relatively high bearing power under all weather conditions to which it is subjected. In this section brick roads have been constructed directly upon the sand subgrade with fairly satisfactory results.

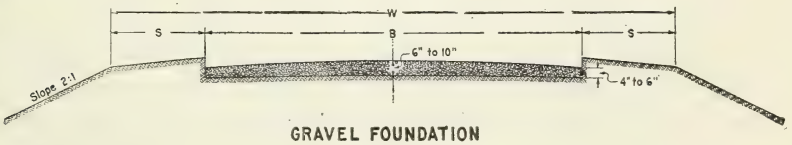
In this region where frost in the ground is unknown, it is necessary to provide only adequate bearing. The requirements of this nature should, however, receive careful consideration and types should be selected that can be repaired easily and successfully without loss of good material, in case the assumed bearing value of the soil is not developed in practice or decreases owing to deterioration of curbs, drying out of sand, or other strictly local causes.

Under the conditions usually prevailing neither the thickness of the road crust nor the combined depth of surfacing and foundation is adequate to prevent entirely the upheaval by frost, providing this is sufficiently extreme. The question of combating frost action still remains unsettled and exceedingly difficult of solution. The damage caused by it is very great in some cases and the economic aspect of the matter is involved. In general, it is not advisable to prepare elaborate and costly foundations to save comparatively cheap roads from slight damage; on the other hand, a considerable expense in foundation construction would be warranted if assurances existed that the effect would be to save an expensive surface from all damage. The entire question doubtless hangs on the reduction of soil moisture in the premises and the removal of free water at all times. To effect this the various methods of drainage discussed will serve largely if judiciously applied. The use of shoulder drains and ample provisions for relieving the subgrade and foundation near the surface of melted snow and ice in periods of alternate thawing and freezing will go a long way toward accomplishing the results desired. Generally in the northern part of the United States, the glaciated areas have well drained soils and frost action tends to be

local. Such sections as develop difficulties of this sort should be treated individually in order to get the best generally good results at lowest cost.

FOUNDATION TYPES.

The types of foundations in common use for country roads are (1) gravel, (2) crushed stone, (3) V-drains, constructed of field stones, (4) stone base, (5) Telford, and (6) Portland-cement concrete. Selected earth, sand, and cinders also have been used frequently to improve the supporting power of subgrades, but since the addition of such materials makes no essential difference in the general method of preparing the subgrade, they will not be considered as foundation materials. Road foundations have been constructed of brick, boards, corduroy, and many other special materials, and such construction is no doubt sometimes justified, although it is usually of a makeshift nature. In these cases the problem generally is concerned with employing local materials which may be secured at small cost and is one to be solved on the ground or after all the affecting conditions have been considered.



GRAVEL FOUNDATION

FIG. 14.

From what has been said it is evident that no very exact rules can be stated for determining what, if any, type of foundation should be selected as best for a general case. Foundation troubles are commonly local and peculiar and yield most readily to special treatment. The considerations that should influence the judgment in making a selection for a particular case are efficiency, and availability of materials, and cost of construction. It is possible to design foundations of any type mentioned above which would be efficient for any given condition of subgrade and type of road crust, but considerations of economy usually will serve to reduce the number of practicable types, for any particular case, to not more than two or three at most.

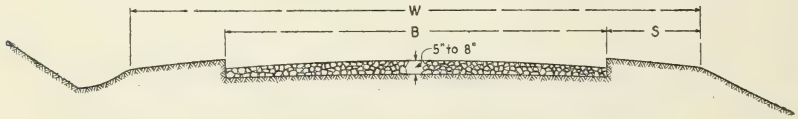
In general, gravel foundations are adapted to cases where the road crust also is to be of gravel or some other simple type, or where only slight additional stability is required for the subgrade to support concentrated loads on the road surface without being deformed. But, if the gravel possesses high cementing value, it may be used satisfactorily for foundations where crushed stone or concrete otherwise would be required. (Fig. 14.)

Crushed-stone foundations have been used for practically all types of road crusts where the subgrade conditions are favorable and a

good quality of stone is available. Such foundations usually are well adapted for road crusts of gravel, macadam, bituminous concrete, and, where the traffic is only moderate, for brick. (Fig. 15.)

The V-drain foundation is adapted to locations where field stones are readily available and where drainage of the subgrade is an essential function of the foundation.

Stone base is a modification of Telford where quarry spalls and broken stone are used, as in V-drains, but where the subgrade is shaped as for Telford. Such stone should be laid on the subgrade so as to bear firmly and not rock, but need not be broken, coursed, and wedged so carefully as Telford. It is finished with fine material,

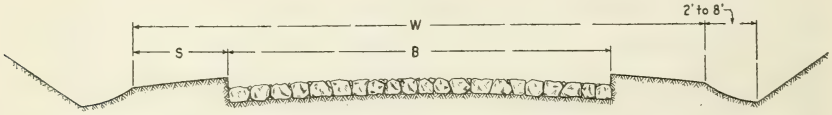


CRUSHED STONE FOUNDATION

FIG. 15.

like gravel, small stone, or sand, and rolled. Its use is similar to that of Telford.

Telford foundations have been used seldom except with macadam or gravel crusts. The reason for this is that the surface of a Telford foundation is irregular and such materials as gravel or crushed stone are well adapted to correcting the irregularities. Such advantage as Telford has over crushed stone foundations lies in the fact that since the individual stones are placed by hand larger stones are used that have greater bearing areas and give better distribution of pressure on the subgrade. This is an important consideration where



TELFORD FOUNDATION

FIG. 16.

the subgrade is not very stable and the necessary rolling of a crushed stone foundation might produce a wavy surface. (Fig. 16.)

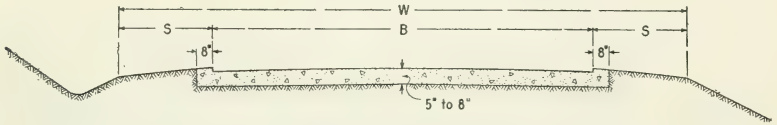
Concrete foundations are well adapted for use where the road crust consists of brick, asphalt, bituminous concrete, or any other material whose integrity and stability can be maintained only when extreme rigidity is supplied by the foundation. In addition to their rigidity, concrete foundations, when properly constructed, present fewer uncertainties due to lack of uniformity in materials and workmanship than any other type, and on that account are greatly to be preferred where the road crust is of an expensive type. Insurance against failure due to lack of uniformity in the subgrade can also, perhaps, best

be provided by means of a concrete foundation, and under extreme conditions of this sort concrete is practically the only satisfactory foundation material. (Fig. 17.)

DESIGN AND CONSTRUCTION.

No matter what type of foundation may be selected for a particular road or section of road it should, of course, be designed and constructed with a view to meeting adequately the conditions involved. Since these conditions vary greatly, sometimes even on the same project, it is manifestly impracticable to standardize either the design or construction of foundations except to a very limited extent. In the following discussion, therefore, no attempt will be made to do more than point out the limits of good design for each type of foundation and to describe, in a general way, what are believed to be the best methods of construction. Thus, unavoidably, much must be left to the judgment of those who design and superintend such work.

Practical experience and observation disclose that the best roads usually have a great variety of foundations. These may have been



CONCRETE FOUNDATION

FIG. 17.

laid at the time of original construction, or added to meet conditions that arise from season to season. For long distances the changes often occur as frequently as every few hundred feet. Rarely are constructed foundations now laid mile after mile, as was done formerly on the pikes of central Kentucky and elsewhere. The cost of such work is so great that the individual and local treatment has more generally been adopted by highway engineers.

GRADING AND PREPARING THE SUBGRADE.

The discussion on bearing power of different soils should be considered in connection with what is said here regarding the proper method of grading a road and preparing the subgrade. The table of bearing powers given on page 41 is based on the assumption that the roadbed and subgrade will be prepared in accordance with some such methods as those described below.

The shape of the subgrade varies somewhat with different types of foundations or road crusts, but this feature does not need to be especially considered here, because the recommended shape for the subgrade is shown for each type of foundation discussed. Where

the subgrade supports the road crust directly the cross section may be either flat or crowned to conform with the finished surface. The flat cross section generally is preferable, because when this shape is used the crown of the road will give a greater thickness of crust at the center where greater strength is desirable. The cross section of course may have any desired crown less than that of the finished surface.

The most important features to consider in forming a roadbed upon which any type of pavement is to be constructed are (1) adequate and effective drainage, (2) firmness and stability, and (3) uniformity in grade and cross section.

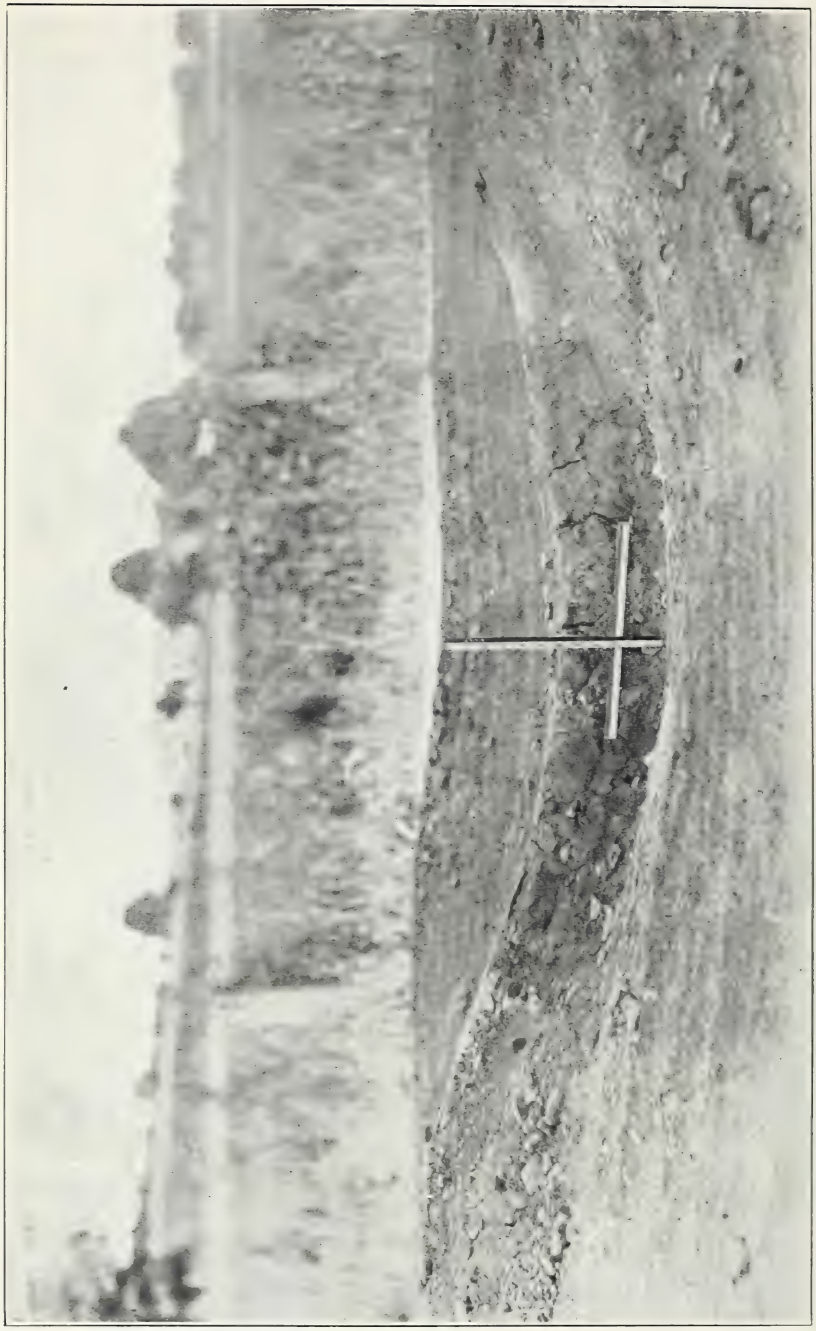
The question of drainage has been discussed separately in this bulletin and it is therefore unnecessary to give this feature further attention, except perhaps to emphasize its importance. This probably can be done best by calling attention to the fact that many earth roads have been converted from almost impassable stretches of mud into excellent driveways for all but extremely bad weather conditions by merely making proper provision for drainage with no other improvement whatever.

The second requirement, firmness and stability, can be secured only after effective drainage has been provided. Soils which absorb moisture readily can not always be drained properly during wet seasons, and should not be permitted to form a part of the roadbed except where full allowance for their reduced bearing power has been made in designing the foundation or road crust. While it is true that for some types of roads foundations are necessary only where soil conditions are unfavorable, it nevertheless is advisable to improve the unfavorable conditions so far as practicable by selecting the best available material for use in the subgrade, even when the very best type of foundation is to be employed. In order that the subgrade may be unyielding it is also necessary for the entire roadbed to be compacted thoroughly. In forming embankments the material should be spread in comparatively thin layers and each layer should be compacted by rolling or by properly directing traffic over it during construction. For this purpose a power roller weighing about 10 tons or a horse roller of less weight may be used. When the grading is substantially completed the subgrade in both excavation and embankment should be brought to its final shape by any suitable devices, and rolled.

Until recent years the preparation of subgrade usually has been done by hand with pick and shovel, and in localities where labor is cheap still may be done so; but quicker and less expensive methods may be used to advantage now. If the grade is to be flat, a drag of railroad iron often is satisfactory. Telford, V-drain, and trench foundations generally can be cut with plow and grading machine

FIG. 1.—U HEAD WALL WITH PIPE CULVERT.

FIG. 2.—CONSTRUCTING V DRAIN.



SETTLEMENT OF PAVEMENT ABOVE PIPE CULVERT

FIG. 1.—DEPRESSIONS OVER UNEVEN BASE.

FIG. 2.—RUTS AND DEPRESSIONS OVER WEAK BASE.

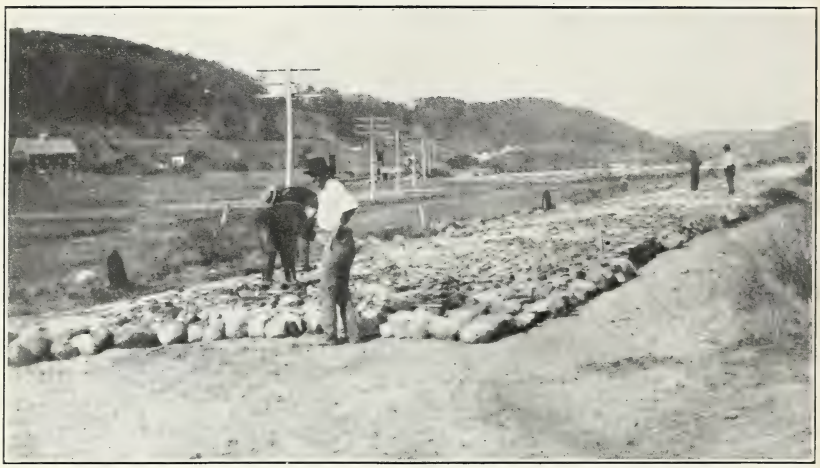


FIG. 1.—LAYING FIELD-STONE BASE.

FIG. 2.—LAYING TELFORD BASE.

and finished with a light drag. Slips, wheelers, or Fresnos may be used with entire success by skillful workmen, and if the heavy grading warrants its presence on the job a steam shovel in the hands of an expert operator can be used to do all but the finishing, which a light drag will do.

It is impracticable to supply detailed instructions as to the best methods for shaping and compacting all kinds of soil, because in many cases experienced judgment is the only safe guide. Where the soil composing the subgrade consists essentially of sand, for example, it may be necessary to wet the subgrade practically to saturation before it can be rolled satisfactorily, and in some cases pipe lines must be provided along the work to supply water for this purpose. On the other hand, clay soils can be rolled effectively only when comparatively dry, and when construction work is proceeding during wet seasons it may be necessary to provide additional facilities for draining the subgrade which would be wholly unnecessary if the work were being done under more favorable weather conditions. No matter what the circumstances of soil and weather may be, the subgrade, when completed, should conform closely in grade and cross section with the requirements of the plans and should present an even uniform surface. It also should be as firm and unyielding as the conditions will permit, because whatever the type of the foundation or the road crust, all loads passing over the surface must be supported ultimately by the subgrade, and unless this feature be sufficient the crust and foundation necessarily must fail.

Some of the most important details which require careful attention in preparing the subgrade, and are perhaps most frequently overlooked, are (1) back filling culvert trenches, (2) exclusion of vegetable matter from fills, (3) provision for draining any wet-weather springs that occur in the subgrade, and (4) the proper handling and use of materials contained in old road crusts which are to be worked into the new construction.

The back filling of culvert trenches is a detail requiring the very closest attention if subsequent settlement of the subgrade and road crust, over the trenches, is to be prevented. Most specifications governing this feature of the work make suitable provisions for having the back fills over all drainage structures properly tamped and compacted, but both engineers and contractors frequently have underestimated the cost of doing such work satisfactorily, and as a result there has been a strong tendency to permit and to do less compacting than the conditions require. The amount of compacting necessary varies, of course, with the character of the soil composing the back fill. Where the soil contains considerable sand or gravel and is moderately moist, it usually may be compacted best by placing the

back fill in layers not over 8 inches thick and thoroughly tamping each layer with a hand tamper.

The thickness of the successive layers and the weight and face of the tamper should be adjusted to produce the most uniform and solid compression reasonably possible. Common practice often is inadequate, sometimes the layers being made a full 8 inches thick and a light one-man tamper being used. On loose and friable soils a broad face is to be preferred, say 8 by 8 inches, and the weight may be raised to 50 pounds if double handles are provided and the work is done by two men.

Where the soil is essentially clay and the trench is deep, the back fill should be deposited preferably in courses and a tamper having a smaller face and weighing 10 to 15 pounds used.

If a clay or silt loam that readily breaks down in water is used, the trench should be filled at first to a depth of not more than 2 or 3 feet, the material being tamped thoroughly as above described, and the partial back fill then may be kept covered with water for several days until the material has become thoroughly saturated and has finished settling. Subsequent layers should be added and "puddled" until the trench is filled completely. Then it should be permitted to stand for several weeks, until the back fill has dried out, before the subgrade is prepared and the pavement constructed. Not infrequently it is cheaper to haul in gravel, or other material which may be compacted readily for use in back fills, rather than to replace clay according to the method above described. In some cases, where conditions were unusually bad, concrete has been used as a back-filling material. Plate VI shows a characteristic failure of a pavement over a culvert where the back fill had been poorly made.

The exclusion of vegetable matter from embankments is nearly always provided for in specifications covering road-improvement work, but in a great many cases the importance of this detail does not seem to be realized. As a rule, no especial harm results to a road from vegetable matter being placed in the slopes of embankments, because unequal settlement of the slopes would not necessarily injure the road surface. When sod and roots are placed in the subgrade, however, even in very small quantities, serious damage to the surface may result from the porosity caused by the eventual decay and shrinkage of the vegetable matter. Further, roots near the edges of the surface are very likely to live and grow, and the result is a weakening of subgrade on a line where the pavement is especially exposed to damage.

Wet-weather springs are not always in evidence at the time a road is being graded, and it is therefore important that the road be examined carefully during wet seasons in order to locate troubles of this kind. Such springs usually may be drained successfully by means of

ditches filled with stone and provided with suitable outlets or by the use of tiling. Methods of constructing drains of either kind are described in another part of this bulletin.

Where old road crusts or old base of broken stone, gravel, Telford, etc., are to be covered, the disposition of the old construction is important. A highway engineer can commit no greater error than to abandon or destroy an old and well-compacted road crust if it can be used as a foundation for a new road. If the new construction is to be gravel or macadam, the lesser irregularities of the old surface can be filled with gravel or fine stone after the old surface has been swept thoroughly. These patches should be well watered, covered with screenings, and rolled. On a base so prepared the new road can be built. If a bituminous top is to be placed directly on the old crust, lean bituminous concrete can be used to excellent advantage. The old surface should be swept thoroughly, the depressed areas painted with the same bitumen used in the mix, and the patches laid and raked with care. A 3 or 4 foot straightedge with a handhole is convenient in bringing the patch to a true surface uniform with the old. The entire series of patches should be rolled and allowed to set for at least 12 to 24 hours ahead of the topping.

If the new surface is to be wider than the old base or crust, it is more difficult to produce an even surface that will not settle at the edges. In many cases the only practicable disposition of the old crust is to loosen it and either waste the material or salvage it for the new top. Salvage methods usually are expensive.

It should be borne in mind that when the old crust is left undisturbed and simply evened up by the addition of new material, it is difficult to compact the new material as thoroughly as the old, and a tendency to uneven settlement of the subgrade will result. For this reason the greatest care should be used in making the preliminary patches. Plate VII shows the results of neglecting this detail.

In the premises the whole problem of making adequate use of old base is largely one of initial engineering. The grades should be laid with unusual care to take advantage of the old crusts, and where these are thin room should be left for necessary additional material.

Where practicable it is always well to have the grading and drainage structures for an improved road completed some time in advance of the pavement. This enables the roadbed to settle without doing any damage, and obviates the necessity for much of the tamping and compacting which otherwise would be necessary.

COST OF SUBGRADE PREPARATION.

The cost of preparing the subgrade of a road to receive the foundation or road crust depends to a very considerable extent on the degree

of care exercised in doing the rough grading, and to a less extent on the type of road crust or foundation which it is proposed to employ. The character of the soil composing the roadbed also may be an important consideration in estimating the cost of this work, especially if any considerable period of time elapses after the completion of the rough grading before the subgrade is prepared. Some soils remain loose indefinitely and are easily worked into proper shape, while others may become hard and compact in a very short time after being placed in a roadbed.

The following examples of road-improvement projects completed under the supervision of the Bureau of Public Roads have been selected to illustrate how the cost of subgrade preparation varies with the local conditions.

Example No. 1.—A macadam road in Montgomery County, Md.
Area surface, 47,456 square yards.
Character of soil, stiff clay.
Grading done with steam-shovel outfit and not very carefully finished.
Cost of preparing subgrade, 6.8 cents per square yard.
Work done with pick and shovels.
Cost includes necessary rolling.

Example No. 2.—Several sections of gravel road in Leflore County, Miss.:
Aggregate area surfaced, 189,535 square yards.
Character of soil, light loam.
Grading done with scrapers and fairly well finished.
Cost of preparing subgrade, approximately, 1.4 cents per square yard.
Work done with road grader and a limited amount of plowing required.
Cost includes necessary rolling.

Example No. 3.—A gravel road in Bexar County, Tex.
Area surfaced, 100,000 square yards.
Work consisted in scarifying and reshaping an old gravel road, and was done by means of a roller with scarifier and road grader.
Cost of preparing subgrade, 3.8 cents per square yard.
Cost includes picking out large stones that were turned up in scarifying, as well as all necessary rollings.

Example No. 4.—A concrete road in Licking and Muskingum Counties, Ohio: Length of road, 24 miles; width of concrete surface, 16 feet; character of soil, stiff clay. The rough grading was done with steam-shovel equipment and scrapers, and the work was in progress during 1914 and 1915. During 1914 the subgrade was prepared almost immediately after the rough grading was completed, and the average cost of its preparation was approximately 3 cents per square yard. During 1915 the rough grading was completed several months in advance of the subgrade, and the average cost of preparing the subgrade was approximately 7.5 cents per square yard. This large difference in cost is attributable partly to the fact that several washing rains occurred between the time of completing the rough grading and the time of preparing the subgrade, and the work charged to subgrade preparations really included a considerable amount of rough grading made necessary by erosion of the roadbed.

GRAVEL FOUNDATIONS.

Gravel for use in road foundations should consist of sound, durable pebbles mixed with sufficient cementing material to bond the individual particles together firmly when the gravel is spread and rolled. Clay is the only cementing material carried by most gravels as they occur in nature, though there are a few deposits that contain other cementing agents, such as iron oxide, lime carbonate, etc. Foundations bonded with the latter materials are much more reliable than those in which the binder is composed essentially of clay. The ordinary gravel foundation with clay binder is used in general only where the wearing crust is to be of gravel also, while if the binder consists of some stable mineral cement, properly constructed gravel foundations may be employed with brick, bituminous concrete, or other highly improved types of road crusts.

It is customary to require that gravel used in foundations shall contain from 60 to 75 per cent, by weight, of pebbles ranging in size between such as will be just retained on a ⅛ or ¼ inch screen and such as will just pass a 2½ or 3 inch screen, and that the remainder shall consist of sand combined with some suitable cementing material. Where clay is the cementing material it should not comprise less than about 15 per cent nor more than about 20 per cent of the total weight. It is important that the gravel be evenly graded in size from fine to coarse and that the cementing material be uniformly distributed through the mass, because poor grading or poor distribution of the clay content evidently would tend to produce unequal density of the foundation.

It very often happens that, in order to be made suitable for use in a road foundation, natural gravel must be screened to remove a part of either the fine or coarse material so as to keep the different percentages within the limits mentioned above. It also is necessary sometimes to wash the gravel in order to remove excessive clay, but this process is expensive, and it generally is practicable to secure the desired results in some other way. When it is necessary to add clay it should be done as the gravel is placed by spreading a uniform layer of clay over each course of gravel and mixing the two together by harrowing.

If this is necessary, it must be done with the utmost care and great thoroughness. When it is realized that one load of clay to a hundred of gravel increases the clay content approximately 1 per cent, it is seen how difficult it may be to raise the clay a few per cent throughout an entire job. Almost always too much is added, and the distribution is exceedingly uneven. To obtain good results the clay should be as dry as possible, well pulverized, and distributed broadcast with shovels just as screenings are on a macadam road. This

clay should be shaken down dry with a harrow and in no case wetted and rolled until the whole mass is well mixed. If large quantities of clay are to be added it is better to place it in a layer between a first and second layer of the cleaner gravel. The foundation then can be wetted and rolled without preliminary harrowing, and the clay will not stick to the roller wheels. Wet clay in contact with the roller can almost never be mixed into the gravel, and endless trouble results from permitting it to occur.

Gravel foundations vary in compacted thickness from about 4 inches up to about 10 inches, depending on the condition of the subgrade and the character of the road crust, as well as somewhat on the quality of gravel used. The most usual thickness is from 5 to 7 inches. Except that where the road crust is to be of some highly improved type a thickness of about 8 inches generally is used. In general, foundations of more than about 5 inches in thickness must be constructed in two or more courses, as otherwise, unless the percentage of clay is unwarrantably high, it is almost impossible to produce a thorough bond between the particles by harrowing and rolling. Figure 14 shows a typical cross section for a gravel foundation upon which the limiting dimensions are indicated. This cross section shows the subgrade and foundation crowned to conform with the surface of the finished road, and probably is more frequently employed than any other form, but in some cases the subgrade is made flat, or even slightly "dished," and the whole crown of the road made up either in the foundation or the road crust. This latter arrangement provides for additional thickness of the pavement near the center where it usually is desirable to have the greatest strength. The principal precautions to observe in constructing gravel foundations may be described briefly and commented upon as follows:

1. The gravel should be delivered on the work in wagons or cars especially adapted to spreading each load uniformly over that part of the subgrade for which it is intended. Where loads are dumped in one spot and spread later with shovels, as is done frequently, it is almost impossible to secure uniform density of the foundation by subsequent harrowing and rolling. The spots where the loads are dumped will nearly always be more densely compacted than the areas in between and, as a result, uneven settlement soon will develop.

2. Where it is necessary to spread the gravel in more than one course the thickness of the different courses should be approximately the same, except that the first course may be made somewhat thicker than the others because, in general, a thicker layer of gravel may be compacted on the subgrade than when spread over another layer of gravel, although compacted. It usually is impracticable to have the finished thickness of any course greater than about 5 inches, and

in some cases 3 or 4 inches is as much as can be compacted satisfactorily at one time.

3. After each course of gravel is spread it should be harrowed thoroughly with a tooth harrow until the different sizes of particles and the cementing material are distributed thoroughly through the mass. Then it should be rolled repeatedly with a power roller weighing about 10 tons until the different particles are all well bonded together and the surface presents a smooth, uniform appearance. When completed, the surface of each course should appear firm and unyielding and should be such that no particles of gravel will be disturbed by men walking upon it.

4. Where it is necessary to add sand or clay to the gravel, in order to fill the voids, it should usually be done after each course is spread and before it is harrowed. But with some kinds of gravel and where certain types of road crust are to be used, it is permissible to add a limited amount of sand after the harrowing is all done and while the rolling is in progress, so as to secure a denser surface. This usually applies to the top course of the foundation when it is desirable to prevent bitumen, Portland-cement grout, or other similar material used in the surface crust from being wasted by penetrating into the foundation.

5. Where the binder consists of some material other than clay it may be desirable to sprinkle each course with water while it is being rolled, and even where clay is used as a binder a limited amount of sprinkling may be necessary in dry weather. The sprinkling always should be done uniformly and in such quantities as not to wash the fine material out from the gravel or to soften the subgrade.

6. When the foundation is complete it should be uniform in grade and cross section. If depressions occur under the roller, they should be corrected by adding gravel and continuing the rolling, and this should be kept up until the foundation is able to support the roller, moving back and forth over it, without appreciable waves being formed in the surface. When the rolling is complete the foundation is ready to receive the surface crust immediately.

COST OF GRAVEL FOUNDATIONS.

In estimating the cost of a gravel foundation it is necessary to consider:

1. The purchase price of the gravel it is proposed to use;

2. The cost of delivering the gravel on the work; and

3. The cost of spreading and compacting. The first two of these factors are evidently dependent to a very great extent on local conditions, and their influence on the cost of a given foundation can not be determined except by a study of the given conditions. The following

data are intended to serve only as an aid in making the necessary study:

A. A cubic yard of loose gravel ordinarily weighs between 2,700 and 3,300 pounds, the average weight being about 3,000 pounds.

B. Loose gravel will shrink from 12 to 15 per cent in volume when compacted in a road foundation. In determining the loose volume of gravel required for a given project it is customary to compute the compacted volume and add from 20 to 30 per cent to cover waste, shrinkage, and loss in handling.

C. The average cost of loading pit gravel by hand into wagons is about 20 cents per cubic yard. Where the amount of work to be done is sufficient to warrant the installation of a steam shovel or the construction of a special scaffold so that wheeled scrapers may be used for loading, the cost of this work usually may be reduced, the reduction sometimes amounting to 50 per cent or more.

D. The cost of screening gravel varies greatly according to the character of the pit-run material and the kind of screening equipment employed. Hand screening costs from 25 to 40 cents per cubic yard, while with a properly arranged mechanical screen the cost should not often exceed 15 or 20 cents per cubic yard.

E. The cost of hauling depends on the equipment used and the condition of the road over which the hauling is done. With teams at $5 per day and the roads such that two tons may be hauled at a load, the average cost is about 25 cents per ton mile, or 37½ per cubic-yard mile.

F. The cost of spreading gravel, on five road projects recently supervised by the Office of Public Roads and Rural Engineering, ranged from about 3 cents to about 8 cents per cubic yard. The average cost was about 6½ cents per cubic yard and the average cost of labor was about 20 cents per hour. The wagons used in all cases were built so that they dumped directly upon the subgrade and were designed to spread the material to a considerable extent while it was being dumped.

G. The cost of rolling the gravel on the above five projects ranged from slightly less than one-half cent to about 1 cent per square yard. The average cost was about 0.6 of a cent per square yard. This included only the labor cost and if fuel for the roller and depreciation were considered the average cost probably would approximate 1½ or 2 cents per square yard.

CRUSHED-STONE FOUNDATIONS.

Crushed-stone foundations have been made from practically all kinds of stone ordinarily available for such a purpose; and provided the stone be sound and durable, there is, in general, no occasion for limiting the varieties that may be so used. A moderately soft or brittle stone should prove equally as satisfactory for a foundation as one that is extremely hard and tough and usually would be much easier to crush, as well as to compact, than the hard, tough stone. The only requirements really essential are (1) that the stone shall possess sufficient resistance against crushing to withstand any load likely to come upon it, (2) that it will not be affected by the action of ground water, and (3) that it will bond together under the roller to form a dense, well compacted foundation. These requirements are based on the assumption that the foundation always will be protected from the

wearing action of traffic by some suitable surface crust, but these requirements would not be sufficient for cases where stone from the foundation eventually might form a part of the wearing surface.

In the case of water-bound macadam roads, for example, the so-called foundation course often is considered as a part of the wearing crust, because ultimately the stone of this course is expected to become the surface as the real wearing course is abated by traffic. Or it is expected that scarifying the road periodically when it is necessary to add new material will bring some of the lower course to the surface. This criticism would be applicable, of course, in less degree where it is purposed to maintain the road surface by bituminous treatments, or for water-bound macadam roads maintained properly with a distinct wearing course and with a foundation not essentially a part of the macadam crust.

The proper size of the stone for use in a crushed-stone foundation depends, first, on the depth of the foundation and, second, on the quality of the stone used. In order to have a locking or wedging effect under the roller it is essential that the stone be considerably less in longest dimension than the proposed thickness of the course. In general, no stone is used larger than 4 or 4½ inches, and the maximum screen specified usually is 3 or 3½ inches for a 6 or 8 inch foundation course. If the foundation is 4 inches, the screen usually is specified to have meshes 2½ or 3 inches in diameter. Soft or thinly stratified rocks that are likely to break into tabular fragments are used quite generally in larger sizes than a hard, amorphous rock with cubical or rhombohedral cleavage. If much tabular rock comes through in the tailings, it should be re-run through a lower crusher to produce more fine stone, as such material usually is short on the low sizes. As in the case of gravel, it is customary to fix the size by specifying upper and lower limiting screens which the material shall pass and be retained upon, respectively, and by providing that the stone shall be well graded in size between the limits specified. Where the stone is hard and tough and does not crush to any extent under the roller it is impracticable to make the successive layers of the foundation more than 4 or 5 inches in compacted depth, because it is very difficult to compact a greater depth satisfactorily. In such cases the particles of stone preferably should be of such size that all will pass a screen having circular openings about 2½ or 3 inches in diameter. If, on the other hand, the stone is moderately soft and brittle, the compacted depth of the foundation courses sometimes may be made as much as 5 or 6 inches and the upper limiting screen may have correspondingly larger openings. The lower limiting screen should, in general, be such that the amount of fine particles left in the screen product will be no more than sufficient to fill the voids and produce a dense, well compacted layer when the stone is

spread and rolled. Ordinarily a screen having circular openings from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter should prove satisfactory for moderately brittle stone, while in other cases, where the stone is hard and tough, it may be permissible to omit the lower limiting screen altogether.

Not infrequently it is desirable to screen out certain sized particles from the product of the crusher for use in the road crust or for some other purpose, and in such cases only the larger sizes, with perhaps a part of the dust or screenings, are available for use in the foundation. With some varieties of stone this arrangement may not be objectionable because the large particles will wedge in together under the roller to form a fairly dense, compact foundation. But with other varieties, such as trap rock, for example, the large particles may not lock very readily and it may be necessary to fill the voids with either stone screenings, gravel, or coarse sand while the rolling is in progress, in order to aid in wedging the crushed stone particles firmly in place.

The compacted thickness of crushed-stone foundations varies in practice from a minimum of about 3 inches up to a maximum of about 9 or 10 inches. The small thickness of 3 inches should be used only for light-traffic roads where the subgrade conditions usually are favorable or where the road crust is capable of distributing the pressure under concentrated loads to a considerable extent, while the maximum thickness of 10 inches would be required seldom except where the surface crust is designed to withstand only the wear of traffic and the subgrade is poor. In the past the usual thickness has been about 6 inches, but under the heavy traffic which prevails at present on many of our improved roads the 6-inch foundation frequently has proved insufficient. This is shown by numerous partial or total failures of expensive road crusts, such as brick and bituminous concrete, due to foundation failure. It is believed that with average subgrade conditions and road crusts of the kinds above mentioned, the thickness of crushed-stone foundation should, in general, be considerably increased above the common practice of to-day.

The number of courses in which the stone should be spread and compacted depends on the depth of stone that can be compacted satisfactorily in one course, and, as explained above, this varies with the quality of the stone used. Ordinarily not more than two courses are necessary, unless the foundation is to be of unusual depth.

In some cases it has been found of advantage to use a crushed-stone foundation under a gravel wearing course. A recent design for heavy traffic where unusual speed of construction and immediate service were essential called for an 8-inch compacted quarry-run base and a 4-inch compacted gravel top. This made use of a relatively cheap but unsatisfactory macadam stone and a relatively expensive

but very quick bonding and satisfactory gravel. The soil was poor, being a micaceous clay, and the base was laid in two courses, with the first thoroughly harrowed to shake the finest to the bottom and close the foundation against the clay. No effort was made to close the top foundation course as the gravel topping served adequately to do this.

Figure 15 shows a typical cross section for a crushed-stone foundation and indicates the limiting dimensions used in good practice.

The proper manner of spreading and compacting the stone probably can best be described by stating certain precautions it is necessary to observe in order to secure satisfactory results. In doing this it will be necessary to repeat several of the precautions already mentioned as being applicable to gravel foundations, because the two types of construction are very similar in many respects. In fact, where the gravel used is such as to compact readily without the presence of clay the construction methods are practically the same as when crushed stone is used.

1. The first precaution in constructing a crushed-stone or any other type of foundation, of course, is to see that the subgrade is well prepared of good material and that it is firm at the time the stone is spread.

2. The stone should be delivered in vehicles adapted to spreading it out in a uniform layer to the required loose depth. If such vehicles are not available, the stone should be dumped on platforms and spread to the required depth with hand shovels. This requirement is of especial importance because it is practically impossible to secure a uniformly compacted foundation unless some such method is followed. Where whole loads are dumped on successive spots of the subgrade and spread by merely raking off the tops of the piles thus formed, a dense core will be formed where each load is dumped and the area between cores will be much less dense. When the layer of stone is rolled, the roller will tend to ride on the cores with the evident result that the foundation will not be uniformly compacted and while its appearance may be satisfactory when first completed, lack of uniform density is almost certain to result later in irregularities, and these will continue to occur long after completion of the top or wearing course.

3. If in hauling and spreading the stone, the fine and coarse particles become more or less separated, as frequently is the case, each layer of the foundation should be harrowed with a tooth harrow until the different sized particles are distributed uniformly throughout the mass. When moderate care is used in handling the stone harrowing should not generally be necessary, though with some varieties of stone there seems to be a strong tendency for the dust and fine particles to become segregated while the material is being loaded into vehicles and in such cases harrowing may be very desirable.

4. After each layer of the stone is spread, and harrowed if necessary, it should be rolled with a power roller weighing about 10 tons, until it is thoroughly and uniformly compacted. The rolling should begin preferably at the edges of the road and progress toward the center, and should continue until no appreciable settlement is caused by additional rolling.

5. In general, the voids in the top layer of the foundation should be filled by spreading coarse sand or stone screenings over this layer while the rolling is in progress. With some varieties of rather brittle stone the voids may be filled

fairly well by particles of stone crushing under the roller and in such cases the addition of sand or screenings may not be necessary. The character of the road crust also should be considered in deciding this point.

6. In order to lock the particles of stone together satisfactorily it frequently is necessary to sprinkle a moderate amount of water over each layer of the foundation while the rolling is in progress. This is especially true of limestone where screenings are added after the stone is spread. In all cases where water is used it is merely to flush the fine chips and dust into the interstices and by no means to produce a grouted surface, and it should be applied gently and in such quantities as not to saturate the subgrade and should be done only on sections of the foundations where rolling is in progress.

COST OF CRUSHED-STONE FOUNDATIONS.

The cost of constructing a crushed-stone foundation, after the stone has been delivered on the work, usually can be estimated with a fair degree of accuracy when the conditions affecting the work are understood. If the stone is hauled out in suitable dump wagons and the price of labor is about 20 cents per hour, the spreading can be done at an average total cost of from 6 to 8 cents per cubic yard. Where the stone is dumped on boards and spread by hand this cost ordinarily will be just about doubled.

The cost of rolling varies with the quality of the stone used. If a hard limestone or trap is used, about 100 cubic yards can be compacted per 10-hour day with a 10-ton roller, while with sandstone or soft limestone the quantity compacted per 10-hour day may be as much as 150 or 175 cubic yards. Assuming the loose depth of the foundation at 9 inches and the cost per day of a roller, including labor, fuel, and depreciation, at $12, the total cost of rolling would average from 2 to 3 cents per square yard. The cost of spreading and rolling combined would average from 3½ to 5 cents per square yard.

The cost of quarrying and crushing varies with the character of the stone, the layout of the quarry, and the equipment employed. Some of the largest producers of crushed limestone market their product at about 50 cents per ton, or 65 cents per cubic yard, while in other cases, where the quarry face is shallow and the plant is small, the actual cost of quarrying and crushing sometimes is more than $1 per cubic yard. The following record is of a limestone quarry in Loudon County, Tenn., operated under the supervision of the Bureau of Public Roads in connection with a single road improvement project, may be of assistance in estimating costs for similar work in other localities. The quarry had been faced up, but required heavy stripping, and the presence of numerous clay seams made drilling and blasting expensive. The stone is a dark-blue, tough limestone, very similar in appearance to Knoxville dolomite. The depth of quarry face was from 12 to 18 feet. Blasting was done

with 40 per cent dynamite, fired by means of batteries, and the rock was hauled to the charging platform in dump carts. A 25-horsepower engine and a No. 4½ crusher were used. The record output was 183¾ cubic yards in one day of 14 hours. The bins were of 70 cubic yards capacity with three subdivisions. The scale of wages was:

Superintendent	per day	$4.50
Timekeeper	do	2.00
Quarry foreman	per hour	.20
Drill runners	do	.17½ to .20
Crusher feeders	do	.17½
Crusher engineman	do	.25
Powder man	do	.16
Unskilled labor	do	.15
Water boy	do	.05 to .07½
Cart and driver	do	.25

The items of cost were:

Labor:	
Superintendence	$128.10
Stripping	219.03
Drilling and blasting	412.57
Sledging	798.31
Hauling to and charging crusher	1,306.38
Crushing and screening	326.74
Repairs to crusher	42.80
Sharpening steel and small tools	214.03
Materials:	
Coal	89.45
Oil	11.20
Dynamite, caps, and fuse	261.10
Repairs to crusher	48.70
Small tools	64.70
Finance:	
Interest on investment, depreciation, etc.	475.85
Total	4,398.46
Total stone quarried and crushed, cubic yards	4,932.3
Cost per cubic yard for quarrying and crushing	$0.80

The cost of quarrying and crushing will average at least 25 per cent higher for trap or granite than for limestone where the quarry conditions are similar.

The largest producers of crushed trap seldom can afford to sell their product at less than about 65 cents per ton or 85 cents per cubic yard, f. o. b. plant, and where the stone is quarried in small quantities the actual cost may greatly exceed those figures. For example, nine small trap and granite quarries in the State of Maine, operated

under the supervision of the Bureau of Public Roads, showed a total average cost for crushing and quarrying of about $1.25 per cubic yard. The total quantity of crushed stone taken from the nine quarries was about 55,000 cubic yards.

V-DRAIN FOUNDATIONS.

The proper method of constructing V-drain foundations has already been discussed under "Drainage" on page 37. A typical cross section for such a foundation is shown in figure 13 and the ordinary method of construction is illustrated in Plate V.

TELFORD FOUNDATIONS.

The stone used in constructing Telford foundations should be sound and tough, so that when wedged into the foundation individual pieces of the stone will not crack or be loosened when rolled or when irregularities are broken off with a hammer. Since the relation between the different particles of stone composing a Telford foundation necessarily must be almost wholly mechanical and its rigidity, therefore, depend on the interlocking of slight irregularities in adjacent stone surfaces, it is evident that if the stone lacks in soundness or toughness, the individual particles might be loosened easily by the shearing off of these irregularities, and whatever load came upon stones so loosened would be transmitted almost undistributed, and therefore unreduced, to the subgrade. Such varieties of stone as soft limestone, brittle sandstone, and decayed granite could not, as a rule, be used satisfactorily in a Telford foundation, though, under favorable subgrade conditions, they might be used advantageously in a crushed-stone foundation.

Satisfactory Telford foundations may be constructed of either quarried or field stone. But, in general, quarried stone is to be preferred, not only because it usually is tougher and more durable, but because it is easier to obtain a good mechanical bond between fresh stone surfaces than between those which have been exposed to the weather for some time and worn more or less smooth. It is also easier to secure a firm uniform bearing for pieces of stone having approximately plane surfaces, than where the surfaces are rounded, as is the case with field stone.

The dimensions individual stones should have need not be fixed very definitely, except that the depth should be equal to the depth of the foundation. In general, the length should not be less than the depth nor greater than about twice the depth. If the length is less than the depth the stone will not be in a stable position, while if the length is greater than about twice the depth it is difficult to insure a uniform bearing. The minimum allowable width depends somewhat on the quality of the stone used as well as on the dimensions. Where an exceptionally hard and tough variety of stone is

used it is permissible sometimes to make the minimum width as low as 1½ inches, but for most conditions this minimum should be preferably not less than about 3 or 4 inches. The maximum allowable width is controlled by much the same considerations as the maximum length, and in general, should not be greater than about 9 or 10 inches.

CROSS SECTION.

The cross section of a Telford foundation usually is shaped in one of three ways: (1) The subgrade may be crowned to conform with the surface of the finished road and the depth of Telford made uniform for all parts of the section; (2) the subgrade may be flat and the depth of the Telford increased from sides to center so as to give the required crown; (3) both subgrade and Telford may be given a flat cross section and the required crown secured by increasing the depth of the surface crust from sides to center.

The first method, which is the one most commonly employed at present, has the advantages that the stones do not need to be sorted so as to secure a uniformly varying depth and that any tendency of the subgrade to settle irregularly will be counterbalanced in a measure by the arch action of the tightly wedged Telford.

The second method was the one employed originally and, while it is more expensive than the first, the extra depth it affords at the center may be of especial advantage where the subgrade consists of soil that is hard to drain. If the side ditches are not sufficiently deep to lower the ground water level below the frost line at the center of the road, an additional depth of Telford at this point evidently would decrease the likelihood of heaving due to freezing of the subgrade.

The third method affords practically the same safeguard against frost as the second, but is subject to the objection that the slightest irregular settlement of the subgrade will weaken, rather than strengthen, the mechanical bond between the different Telford stones and thus will increase the tendency for irregularities to develop.

Figure 16 shows a typical cross section for a Telford foundation, and Plate VIII is a photograph illustrating the method of construction.

DEPTH.

The depth of Telford foundations varies in common practice from 6 to 8 inches. Where subgrade conditions are extremely unfavorable it may be advisable to increase the depth above 8 inches, but under no ordinary circumstances should a depth less than about 6 inches be employed, because when the depth is less than this it is hardly practicable to bond the individual stones together securely by wedging and rolling.

CONSTRUCTION.

In constructing a Telford foundation the stones are set by hand on the prepared subgrade so as to break joints roughly in the courses, which should be approximately straight across the road. Each stone should be placed with its long dimension in the direction of the courses and should be bedded evenly on the subgrade. The stones should be set together as closely as practicable and should be wedged firmly in place by means of spalls as the setting proceeds.

Ordinarily, the Telford stone is hauled out and distributed on the subgrade ahead of the men who do the setting, the individual pieces being of such size that they may be handled readily by one man. Then, as the stone is needed for use, it is broken to the required size with sledge hammers and placed in the foundation as above described. Under average conditions two laborers to each stone setter are required to select and carry the stone to where it is needed, and to assist in wedging up the foundation with spalls.

As the wedging proceeds all projections of more than about 1 inch above the intended surface of the foundation should be broken off with hammers and the spalls thus obtained used as wedges. When the laying and wedging are complete, the surface of the foundation should present a fairly uniform appearance and should be free from open or loose joints.

As soon as practicable after the stone is placed the foundation should be rolled with a power roller weighing about 10 tons. If depressions develop under the roller that indicate failure of stone or soft subgrade, they should be corrected by taking up and relaying the affected portions, and the rolling and relaying should continue until no such depressions occur. If the road crust is such as to require a smooth foundation, the irregularities of the Telford may be overcome by spreading a layer of coarse sand or stone screening over the surface while the rolling is in progress. In the past, however, Telford foundations usually have not been employed except in connection with macadam or gravel road crusts, and with these the small irregularities of the Telford surface are not objectionable.

COST OF TELFORD FOUNDATIONS.

The cost of setting Telford varies with the character of stone used. Where the stone is laminated, for example, the individual pieces usually will be such as to fit snugly together and comparatively little wedging with spalls will be necessary. Thin-bedded limestone lays especially well in Telford construction. But if the stone is unstratified, it will break into irregular pieces, and the work of breaking off projections and wedging up the foundation will be increased correspondingly. A study of available data shows that where the stone is

delivered on the work in sizes suitable for handling by one man it can be broken and placed in a foundation of ordinary depth at the rate of from 1 to 3 square yards per laborer per hour. Assuming labor at 20 cents per hour and making a reasonable allowance for overhead charges, the cost of setting and wedging an ordinary Telford foundation may be estimated at from 10 to 25 cents per square yard; the variation being controlled by the character of the stone.

The cost of quarrying and hauling has been discussed in connection with crushed stone and gravel foundations, and it is evident from those discussions that no definite rules for estimating these items can be stated. In localities where Telford foundations have been used extensively the cost of quarrying generally varies between 40 cents and 75 cents per cubic yard, according to the character of the stone and the methods employed, and the contract price for the foundation is between 50 cents and 90 cents per square yard.

CONCRETE FOUNDATIONS.

At present concrete foundations are constructed almost exclusively of Portland cement concrete, and are used generally in connection with such types of road crusts as granite block, vitrified brick, wood block, asphalt, and bituminous concrete. The advantages possessed by concrete foundations for these types are:

1. Properly prepared concrete is more uniformly reliable in distributing the pressure due to concentrated loads than any other material of which road foundations are ordinarily constructed. Concrete foundations are to be preferred therefore, for expensive road crusts such as those mentioned above, which might be damaged seriously by settlement of the foundation.

2. For all practical purposes as foundations concrete is impervious to water and prevents the surface crust from being damaged by the action of ground water, or surface water from percolating through to the subgrade, where either of these conditions otherwise might occur.

3. In case of slightly irregular settlement of the subgrade a concrete foundation may be sufficiently strong to act as a bridge over depressions which, with other types of foundations, would cause irregularities to develop in the road surface. The extent to which a concrete foundation affords these advantages is controlled by the design of the foundation, the selection of the concrete materials, and the care exercised in construction. Each of these features will be discussed briefly.

DESIGN.

Figure 17 shows a typical cross section for a concrete foundation and indicates the limiting dimensions ordinarily used in good practice. A lower minimum depth than 5 inches at the center is used sometimes, but hardly can be justified by experience, except where the surface crust is designed to aid materially in distributing the pressure due to concentrated loads. Plate IX shows an example of failure where a sand-filled brick pavement was constructed on a 4-inch

concrete foundation. An inspection after failure showed that the foundation of this road was made of rather poor grade concrete, and was not uniformly of the required depth, but the completeness of the failure would seem to indicate that even full 4 inches of good concrete hardly would have been sufficient. In this case the subgrade conditions were fair and the road had held up under light traffic for about one year, when failure was caused by a few trips of a loaded motor truck.

The maximum depth of 8 inches is sufficient for all ordinary subgrade and traffic conditions, provided a good quality of concrete is used, and in most cases a depth of 6 or 7 inches has proved entirely sufficient.

Though the strength of a concrete slab increases rapidly with an increase in depth, the conditions affecting the concrete road foundations are so involved that no data now available furnish reasons for a definite conclusion as to the rate of increase. When the probable effects of an increase of depth are all considered, such as greater strength as a simple beam, extra dead-weight to act against frost, additional resistance to cracking under changes of temperature and moisture, additional strength to resist impact, and the lower percentage of scant thickness produced locally by the unavoidable irregularities of subgrade, it is probable that a 6-inch slab foundation will give at least twice the effective service that a 4-inch slab will give.

If it be deemed advisable to employ a greater depth than 6 inches, it usually is permissible to decrease the depth from the center toward the edges. This is done by flattening the crown of the subgrade.

CURBS.

The types of road crust ordinarily requiring concrete foundations also usually require curbs of some kind to protect the marginal portions of the crust from disintegrating under traffic. The curbs may be made of either concrete or stone, and, for country roads, are designed to come flush with the road surface. Stone curbs should have a depth of from 12 to 18 inches, according to the depth of the frost line, and should be set before the foundation is laid. Concrete curbs may be constructed either separately or in combination with the foundation. In the former case they should have a cross section similar to stone curbs and should be constructed in place ahead of the foundation, while in the latter they may be simply flanges on the edges of the foundation, formed of rich concrete poured before the concrete of the foundation has taken its initial set. The proper thickness for both stone and concrete curbs varies somewhat with the conditions involved, but 6 inches is the thickness employed most commonly. Four inches is the minimum likely to prove satisfactory

under even the most favorable circumstances, while 8 inches is sufficient for the worst conditions, except in the case of stone curbs where the stone used is not of very good quality. In the latter case a thickness of as much as 12 inches has been employed.

STEEL REINFORCEMENT.

In a few instances concrete foundations have been reinforced with steel in order to secure the required strength with less depth. But, in general, the use of steel reinforcement has been confined to anchor rods for tying flange curbs on to the foundation. For this purpose one-half-inch rods spaced about 18 inches apart should be sufficient. The rods should extend about 1 foot back into the foundation and should be bent so as to project up into the curb near its inner face.

MATERIALS.

The materials composing Portland-cement concrete are: (1) Portland cement, (2) sand, (3) gravel, crushed stone, or crushed slag, and (4) water. To secure high-grade concrete it is necessary that each of the constituent materials shall possess certain definite qualities. Inferiority in the quality of a single constituent may easily be responsible for complete failure of the concrete in which it is used, and can not be overcome by the relative excellence of the other constituents. While the cement and sand are the two materials most frequently responsible for failures, the coarse aggregate usually composes the bulk of the concrete, and if it is defective a corresponding weakness necessarily must be apparent in the concrete.

In selecting materials for concrete availability is, of course, a very important consideration, but preference for local materials should be exercised only in so far as it can be controlled by such requirements regarding the quality of the materials as are known to have produced satisfactory results. Wherever any doubt exists as to the suitability of some particular material proposed for use in the concrete it should be subjected to such tests as will determine the points in question before its use is permitted. The following brief discussions of the different concrete materials should serve at least as a partial guide in making proper selections.

Cement.—Portland cement is manufactured in nearly every section of the country, and most plants are equipped to turn out a satisfactory product. But the facts that poor cement sometimes may be produced by the most carefuly operated plants, and that good cement is damaged easily by age or exposure make it advisable to subject the cement to very careful investigation before it is used. Suitable specifications for Portland cement have been isued by the United States Bureau of Standards in their Circular No. 33 and by the

American Society for Testing Materials. Since copies of these specifications may be obtained readily the detail requirements which they contain will not be repeated here.

Sand.—The strength of cement mortar depends almost as much on the quality of the sand used as on the quality of the cement. The requirements to which it should conform in order to produce a strong mortar are: (1) It should be clean. Sand which contains more than about 3 per cent by weight of foreign materials, such as clay or loam, is unsuitable for use in concrete. (2) It should be absolutely free from acids. Not infrequently sand banks will become impregnated with acids from decayed vegetable matter which seriously affect the strength of cement, and in order to provide insurance against the presence in the sand of such acids or other similar deleterious matter it is good practice to provide for testing mortar briquettes made of the sand and cement it is proposed to use in the work. (3) The sand particles should be graded in size so that the percentage of voids will be comparatively low, though a sand in which all the particles are moderately coarse usually is considered preferable to one in which very fine particles predominate.

Because of the importance of the sand and the practical difficulties in grading it in large quantities it is customary to specify certain general physical tests, usually such as may be made with a set of hand screens, and in addition requiring that it shall develop a strength equal to or bearing a specified relation to a definite standard. A satisfactory specification is to require the dry sand to pass a one-quarter-inch mesh, that not more than 20 per cent by weight shall pass a sieve having 50 meshes to the linear inch nor more than 5 per cent shall pass one having 100 meshes per inch. Sometimes it is specified that not more than 60 per cent nor less than 20 per cent shall be retained on a sieve having 20 meshes per inch. Comparison with the mortar made with Standard Ottawa sand and the same cement in the same proportions and under like conditions is generally specified, to the end that the sand as it runs shall develop at least as good results as the standard sand. For detailed specifications see United States Department of Agriculture Bulletin No. 249, Portland Cement Concrete Pavements for Country Roads.

Coarse aggregate.—Coarse aggregate for concrete to be used in road foundations may consist of crushed stone, crushed slag, or gravel. It is claimed that coarse aggregate consisting of angular-shaped particles, such as crushed stone or slag, possesses some advantages over gravel because of the better bond secured between the individual particles and the mortar of the concrete. This claim seems at least partially justified by the fact that foundations constructed of gravel concrete usually have cracked somewhat worse than when the other materials have been used as coarse aggregate,

but it is doubtful if the difference would warrant any very expensive discrimination against gravel so far as concrete foundations are concerned.

No matter what kind of coarse aggregate is used it should consist of sound particles of at least moderate toughness, and should be practically free from clay, loam, and other foreign matter. In general, the specification for coarse aggregate should be drawn with a view to securing the best material available, and not merely to exclude material of a known unsatisfactory character.

The difficulties experienced in securing satisfactory coarse aggregate frequently are due to a lack of facilities for preparing the natural materials available locally, rather than to any lack of natural materials. There are few gravel pits, for example, which furnish gravel suitable for use as concrete aggregate without washing, and this process, to be carried on economically, requires a rather expensive plant. It is necessary also that stone be quarried, and slag must be selected carefully; and, moreover, both must be crushed before they are suitable for use as concrete aggregate.

The size of the particles composing the coarse aggregate is an important consideration and usually is fixed by specifying upper and lower limiting screens which the coarse aggregate shall pass and be retained upon respectively. Experience has shown that for concrete fundations the largest particles of coarse aggregate should be such as just pass a screen having circular openings equal in diameter to not more than one-third or less than about one-fourth the depth of the foundation. The lower limiting screen should have openings of from one-quarter to one-half inch in diameter according to the amount of fine particles present in the unscreened material. It is very desirable that the particles be graded in size between the upper and lower limits specified so as to secure a dense mass. This perhaps may be best assured by providing that not less than a certain percentage of the coarse aggregate shall pass and not less than a certain percentage be retained upon a properly selected intermediate screen.

Water.—The water used in mixing concrete should be reasonably clear and practically free from alkalies, acids, vegetable matter, or other injurious materials. Ordinarily very little difficulty is experienced in obtaining suitable water.

PROPORTIONING.

The proportion in which the materials should be mixed for concrete to be used in road foundations depends, theoretically, upon the percentages of voids in the sand and coarse aggregate. In theory, the amount of cement should be just sufficient to fill the voids in the sand and coat the individual sand grains with cement paste, and the

amount of sand and cement mortar should be just sufficient to fill the voids in the coarse aggregate and coat the individual particles of aggregate with mortar. In practice, the percentage of voids varies considerably, especially in the coarse aggregate, even with materials from the same source, and it is impracticable to vary the proportions to correspond with the voids. It is customary, therefore, to fix a definite proportion, by bulk, in which the materials shall be mixed, without further reference to the voids than to consider the general nature of the aggregates it is purposed to use. This arrangement works out satisfactorily, provided the proportion be chosen intelligently.

The percentage of voids in concrete materials average about as follows:

	Per cent.
Sand	30 to 40
Gravel	30 to 45
Crushed stone	35 to 50
Crushed slag	40 to 50

The proportions most commonly used for road foundations are, where the coarse aggregate consists of gravel, 1 part of cement, $2\frac{1}{2}$ parts of sand, and 5 parts of gravel, or 1 part of cement, 3 parts of sand, and 6 parts of gravel; where crushed stone or slag is used as coarse aggregate, 1 part of cement, 3 parts of sand, and 5 to 6 parts of coarse aggregate. Sometimes, when it is purposed to use especially well graded coarse aggregate and great strength for the concrete is not deemed necessary, it may be permissible to specify a proportion of 1:3:7, but in general, no concrete leaner than 1:3:6 should be used in road foundations without first making a series of tests to demonstrate whether satisfactory results may be secured by using a smaller proportion of mortar.

CONSISTENCY.

The two considerations that should determine the consistency of freshly mixed concrete to be used in road foundations are: (1) It should be sufficiently wet to be spread, shaped, and compacted with facility. (2) It must not be mixed so thin as to lose its crown or to flow on grades after it is struck off and shaped. It has been claimed frequently that a rather dry mixture, provided it is properly tamped, makes stronger concrete than wet mixture, and this claim no doubt is partly true. But the additional tamping necessary to secure a dense mass, together with the extra difficulties involved in striking off and shaping the dry mixture, add considerably to the cost of doing the work, and it is doubtful if the advantage gained is commensurate with this extra cost. When the concrete will hold a crown of at least one-quarter inch to the foot immediately after it is placed

in the foundation, struck off and shaped, it is not at all likely to be seriously defective in strength on account of the mixture having been too wet. The consistency necessary to meet this requirement frequently is described in specifications as "jellylike."

The amount of water required to produce a jellylike consistency varies with the condition of the aggregates as well as with the amount of mixing a batch of concrete receives. In general, the better the concrete is mixed the less water is required, and the amount of water used for each batch should be just sufficient to produce the desired consistency when the batch has been mixed thoroughly. This amount can be best ascertained by trial, and frequently must be modified from time to time as the work progresses.

CONSTRUCTION.

The different steps involved in constructing a concrete foundation should proceed in the following order: (1) The subgrade should be prepared in accordance with the method already described. (2) The materials should be hauled out and deposited on the subgrade. (3) The concrete should be mixed, placed, and properly finished. (4) The foundation should be kept closed to all traffic for about 10 days, and protected from too rapid drying out by a covering of earth or other suitable material. (5) The earth covering is removed and the foundation is ready to receive the pavement.

Curbs are not mentioned above, because the order in which they are constructed depends on the type employed. If the curbs are separate from the foundation they should be constructed while the subgrade is being prepared and before the foundation materials are hauled out. If constructed as flanges on the foundation, the outside forms should be set as the subgrade is prepared and then side forms while the concrete is being placed. Forms may consist of either 2½-inch wooden boards or of steel channels, though the steel is to be preferred. The forms should, of course, be set true to line and grade and should be well braced so as to resist springing out of shape when concrete is placed against them.

The materials may be hauled out in any one of several different ways. From the standpoint of economy alone, teams ordinarily would be used for small quantities of work and moderately short hauls, tractors or motor trucks for good roads and long hauls, and industrial railways where the roads are poor and the quantity of work to be done is sufficient to warrant the purchase of the necessary equipment. From a standpoint of excellence, the industrial railway is preferable to the other methods, because hauling over an industrial railway would not disturb the prepared subgrade in any way, while with the other methods it usually is impracticable to prevent the sub-

grade from being more or less damaged. Where hauling over the prepared subgrade is permitted it always tends to produce a lack of uniformity by increasing the degree of compactness of the parts traversed, and this may result easily in unequal settlement with consequent cracking of the foundation and road crust.

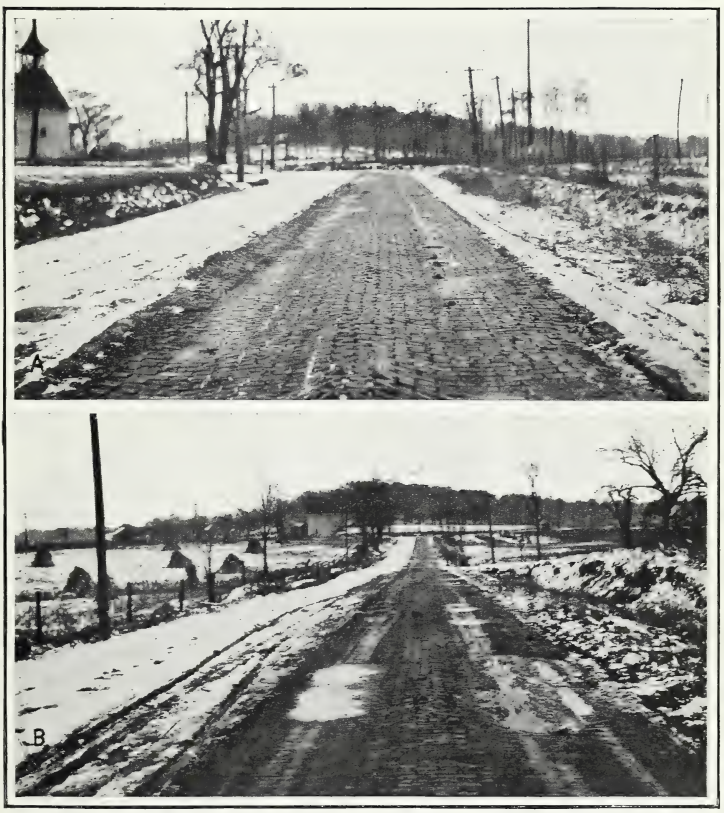
If the locality of the construction is one where rains are heavy and frequent, or in a season having such rains, judgment should be exercised in placing the materials on the subgrade very far in advance of the time they are needed for use, because under such conditions the subgrade may become saturated under the material piles and not dry out before the concrete is placed.

According to present practice concrete for road foundations is almost invariably mixed in a machine mixer. Hand mixing can be afforded only where the work to be done is inconsiderable and rarely produces as uniform concrete as machine mixing. In this discussion, therefore, it will be assumed that a machine mixer is employed in all cases. To accomplish satisfactory work under the conditions met ordinarily in foundation construction the concrete mixer should possess the following features: (1) It should be of the batch type, so that uniform proportioning of the material may be assured; (2) it should be fitted with a traction attachment so that it may be moved along the road under its own power as the work progresses; (3) it should include a device for distributing the concrete. This device may consist of a boom with a bucket traveler, a chute, or a revolving tube. The boom and bucket is to be preferred generally because it enables a greater area of foundation to be placed from one position of the mixer than either of the other devices, and consequently machines so equipped require less moving than others.

Sometimes the concrete is mixed in a stationary mixer and hauled to its place in the foundation, but this method is objectionable because it permits a separation of the component materials to take place between the time of mixing and the time of depositing. If a uniformly dense concrete is to be produced it must be deposited in the foundation immediately after it is mixed. Failure to secure uniform density impairs the strength of the concrete, and, in extreme cases, may cause cracks to develop in the foundation, thus greatly lessening its power of distributing stresses due to concentrated loads.

The principal precautions essential to observe in mixing and placing concrete in a road foundation are to see—

1. That the amount and time of mixing is sufficient to secure a thorough distribution of the different materials through the mass and complete hydration of the cement. Tests have shown that increasing the time a batch of concrete remains in the revolving drum of a mixer, within reasonable limits, has very much the same effect as increasing the proportion of cement. The efficiency with which mixers work, as expressed in the strength of concrete, varies



ABOVE: SAND-FILLED BRICK ON CONCRETE FOUNDATION. BELOW: FAILURE OF SAND-FILLED BRICK ON 4-INCH CONCRETE BASE.

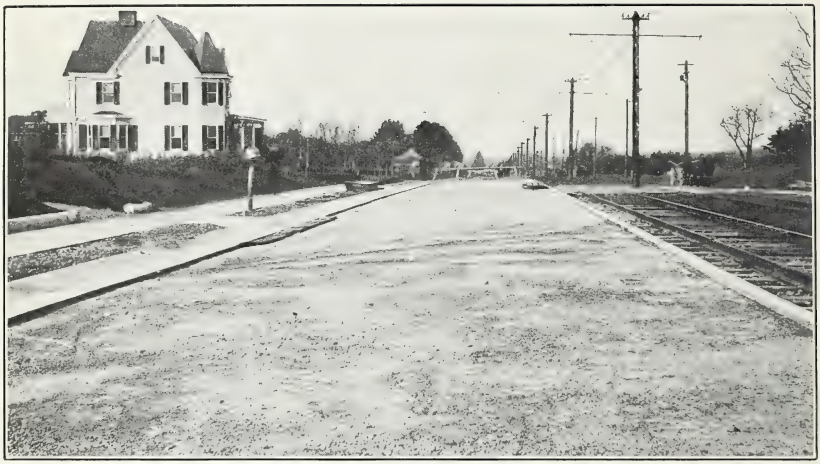
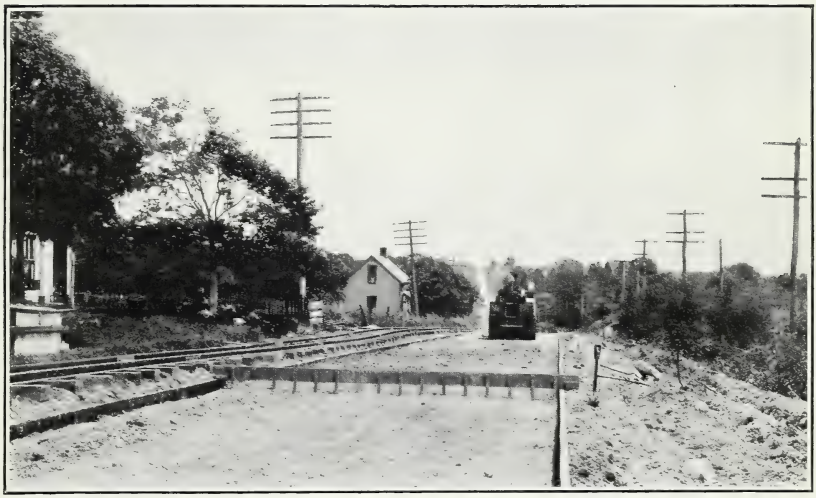
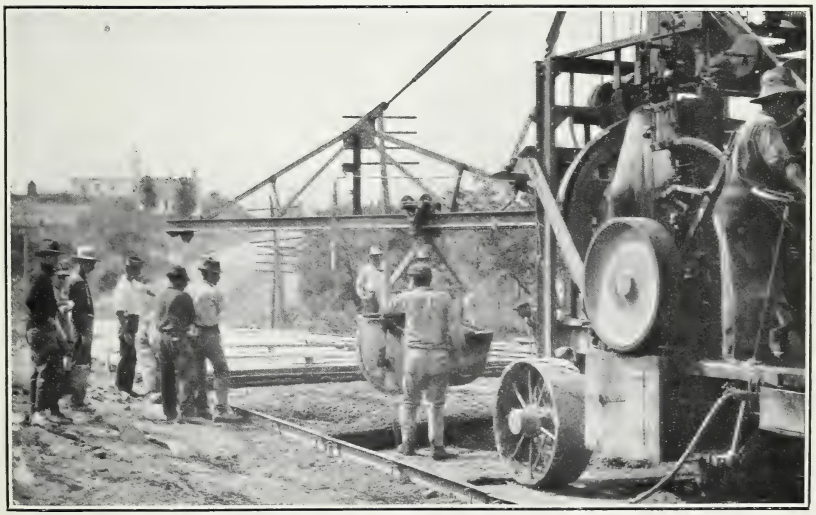


FIG. 1.—CONCRETE FOUNDATION WITH MARGINAL CURBS READY FOR WEARING SURFACE.

FIG. 2.—CONCRETE GUTTER, SHOWING RELATION TO FINISHED HIGHWAY.





CONCRETE FOUNDATION CONSTRUCTION.

CONCRETE ROAD CONSTRUCTION.

rather widely. With the average batch mixer, the minimum time should not be less than about one minute and about 14 or 20 turns of the drum, and if practicable, an automatic timer or counter should be employed to see that this minimum is observed.

2. That the subgrade is damp when the concrete is placed upon it. A special hose should be provided for sprinkling the subgrade and the sprinkling should be done in such manner as not to produce mud. The object of wetting the subgrade is to prevent it from absorbing the water of the concrete, and the amount of sprinkling should be only sufficient to accomplish this purpose.

3. That the concrete is placed with dispatch after it is mixed, and that it is of such consistency that it may be struck off immediately and shaped without danger of the layer becoming wavy or otherwise losing its shape. The concrete should be compacted as it is struck off. This may be done by using the strike board as a tamper, or by some other suitable device.

4. That no concrete is laid during freezing weather and that none of the materials used contain frozen lumps. Freezing of fresh concrete may cause complete failure and nearly always impairs its strength. After concrete has set for four or five days, it is not likely to be damaged by freezing.

5. That the new concrete foundation is protected from too rapid drying out by a covering of earth or other suitable material. The earth covering should be at least 1 inch thick and should be spread as soon as may be without damaging the concrete (ordinarily about 24 hours). The covering should remain on the foundation for about 10 days and should be sprinkled repeatedly and kept moist during this period. No loads whatever should be permitted on the foundation until it is 10 or 12 days old. The earth covering is of especial importance during the hot, dry seasons of summer but is sometimes omitted altogether in the spring or fall seasons when weather conditions are favorable.

6. That no heavy loads are allowed on the foundation until after the road crust has been completed and opened to traffic.

Plates XI and XII illustrate the different steps involved in the construction of a concrete foundation.

SPECIAL CONCRETE FOUNDATIONS.

In addition to the general method described above for constructing concrete foundations, several special methods have been tried, but none of these has proved of sufficient importance to warrant a detailed description. In one or two instances attempts have been made to mix the concrete in place on the road. According to this method, the materials were spread out in proper proportions, water added, and the mass mixed by means of harrowing. According to another method the coarse aggregate is spread and rolled as for a crushed stone foundation, and the voids in the mass then filled, as nearly as practicable, with Portland cement grout mixed very thin and poured over the surface.

A modification of the common method has been employed lately in connection with brick pavement construction. The modification consists essentially in laying the brick before the concrete of the foundation has had time to set, and is really concerned more with the road crust than the foundation. This method promises to be of importance, but since its application is limited at present to only one

type of road, and since it has already been described in the office publications on brick road construction, it will not be discussed further here.

COST OF CONCRETE FOUNDATIONS.

In estimating the cost of a concrete foundation it is necessary to consider the materials and the labor separately. Table 12 shows the quantities of the different materials required to build 100 linear feet of foundation 6 inches thick for the various proportions of mix ordinarily used in foundation construction. In preparing the table the percentages of voids in the coarse aggregate have been assumed as 35 and 45, respectively, for well-graded gravel and average crushed stone. The sand is assumed to be moderately well graded and each barrel of cement is assumed to have a volume of 4 cubic feet.

TABLE 12.—*Showing quantities of materials required for 1 cubic yard of concrete.*

Cement.	Sand.	Coarse aggregate.	Coarse aggregate to be well-graded gravel or equivalent.			Coarse aggregate to be average crushed stone or equivalent.			
			Cement.	Sand.	Coarse aggregate.	Cement.	Sand.	Coarse aggregate.	Width (6 inches thick).
			PROPORTION.						
1	2	4	*Barrels.* 1.38	*Cu. yds.* 0.41	*Cu. yds.* 0.82	*Barrels.* 1.51	*Cu. yds.* 0.45	*Cu. yds.* 0.90	*Feet.*
1	2½	5	1.13	.42	.84	1.24	.46	.92	
			QUANTITIES.						
1	2	4	23.00	6.83	13.67	25.17	7.50	15.00	9
			35.78	10.63	21.26	39.15	11.67	23.34	14
			46.89	12.15	24.30	44.74	13.33	26.67	16
			46.00	13.67	27.33	50.33	15.00	30.00	18
			51.11	15.18	30.37	55.93	16.67	33.33	20
1	2½	5	18.83	7.00	14.00	20.67	7.67	15.33	9
			29.30	10.89	21.78	32.15	11.93	23.86	14
			33.48	12.44	24.89	36.74	13.63	27.26	16
			37.67	14.00	28.00	41.33	15.33	30.67	18
			41.85	15.55	31.11	45.93	17.04	34.08	20
1	3	5	17.83	7.83	13.17	19.33	8.67	14.33	9
			27.75	12.19	20.48	30.08	13.48	22.30	14
			31.70	13.93	23.41	34.37	15.41	25.48	16
			35.67	15.67	26.33	38.67	17.33	28.67	18
			39.63	17.41	29.26	42.96	19.26	31.85	20
1	3	6	16.17	7.17	14.33	17.67	7.83	15.67	9
			25.15	11.15	22.30	27.49	12.19	24.37	14
			28.74	13.74	47.48	31.41	13.93	27.85	16
			32.33	14.33	28.67	35.33	15.67	31.33	18
			35.93	15.93	71.86	39.26	17.41	34.82	20
1	3	7	14.67	6.50	15.17	.....	.....	.....	9
			22.82	10.11	23.60	.....	.....	.....	14
			26.07	11.56	26.96	.....	.....	.....	16
			29.33	13.00	30.33	.....	.....	.....	18
			32.59	14.44	33.70	.....	.....	.....	20
			PROPORTIONS.						
1	3	5	1.07	0.47	0.79	1.16	0.52	0.86	.....
1	3	6	.97	.43	.86	1.06	.47	.94	.....
1	3	7	.88	.39	.91	.....	.....	.....	.....

In purchasing sand and coarse aggregate for concrete the unit of measure is quite frequently the ton instead of the cubic yard. After the quantities have been estimated from the preceding table, therefore, it may be necessary to convert cubic yards into tons before the cost can be estimated. This can not be done accurately without some definite knowledge as to the relative heaviness of the materials it is purposed to use, but the following list of average weights will afford a means of making an approximate conversion. In using this list it should be remembered that the extreme variations in weights of crushed stone may be as much as 10 per cent in either direction from those shown.

Approximate average weights per cubic yard of various concrete materials.

	Pounds.
Standard Ottawa sand	2,500
Average clean bank	2,600
Well-graded clean bank sand	2,900
Average washed gravel	2,700
Well-graded washed gravel	3,000
Crushed limestone screened between ½ and 2 inches	2,500
Crushed sandstone screened between ½ and 2 inches	2,400
Crushed granite screened between ½ and 2 inches	2,700
Crushed trap screened between ½ and 2 inches	2,800

The cost of quarrying and crushing stone has been discussed in connection with crushed-stone foundations, and need not be discussed further here except to state that stone for use as concrete aggregate must be screened more carefully than when intended merely for use in a crushed-stone foundation. The additional cost occasioned by this extra care should not exceed about 5 or 6 cents per ton where adequate machinery is employed.

In discussing gravel foundations some information as to the cost of screening has been included. In a well-arranged plant the cost of washing and screening should scarcely exceed the average cost for screening alone. Large producers of washed gravel ordinarily market their product at from 30 to 40 cents per ton f. o. b. at the plant. Where the supply of gravel is limited, or the demand is small, the price may be increased greatly; sometimes to more than twice what is given above. The cost of sand at the pit averages about the same as that of gravel.

The cost of mixing and placing concrete may be estimated from the labor required to operate an ordinary street-paving concrete mixer, considered together with the mixer's capacity. There are two sizes of such mixers in common use. The larger size has a batch capacity of about one-half cubic yard and requires about 35 laborers of all classes for its efficient operation, while the batch capacity of the smaller size is about one-third cubic yard and the number of laborers

usually employed in operating it is about 30. The hourly output of the larger size should average about 18 cubic yards of concrete and of the smaller size about 12.5 cubic yards. Assuming the cost of labor at 20 cents per hour and making a reasonable allowance for depreciation of equipment and supervision, the cost of mixing and placing the concrete may usually be estimated at from 60 to 80 cents per cubic yard.

NOTES ON SPECIFICATIONS.

The following notes on specifications are given as typifying what is believed to be the best practice so far developed in connection with the various features of highway improvement that have been discussed in the preceding pages. These notes are given with a view to making the information contained in the text readily applicable to contract work. In order to avoid repetition the notes on materials are separated from those on the methods of construction.

MATERIALS.

Cement.—The cement for use in this work shall meet the requirements of the standard specifications for Portland cement of the American Society for Testing Materials, adopted in 1904 and revised in 1916, serial designation C9–17.

Provisions are made in these specifications for testing and storing the cement. Under certain conditions, if the cement meets the 7-day tests satisfactorily, it need not be held until the results of the 28-day tests are available.

Fine aggregates: Sand. (See Bulletin 555, p. 19.)

Stone or gravel screenings. (See Bulletin 555, p. 10.)

Coarse aggregates: Broken stone or gravel. (See Bulletin 555, p. 9.)

Broken slag. (See Bulletin 555, p. 15.)

Cushion or bedding: Sand. (See Bulletin 555, p. 21.)

Granulated slag. (See Bulletin 555, p. 15.)

Grouting sand. (See Bulletin 555, p. 20.)

Water.—The water used in the mixing of concrete or grout shall be free from oil, acid, alkali, or vegetable matter, and fairly free from clay or silt.

Cobblestones.—Cobble paving shall be constructed of bank or river cobbles, sound in all respects and fairly symmetrical in shape. No stone shall be used which is less than 6 inches or more than 10 inches in its longest dimension or which does not have one lesser dimension at right angles to the length of at least 4 inches. If preferred by the contractor, quarried stones which, in the judgment of the engineer, are equal to the cobbles above specified, may be substituted for the cobbles, provided that the limiting dimensions of the individual blocks of quarried stone shall be the same as those specified for cobbles.

CLAY FARM DRAIN TILE.

NOT EXCEEDING 12-INCH DIAMETER.

[Copied largely from A. S. T. M. Standard Specifications C4–16.]

The tile shall be made from shale, fire clay, or surface clay by such method of manufacture as will insure excellence of product and uniformity in quality.

The presence in the tile of visible grains or masses of caustic lime, iron

pyrites, or any other minerals which are known to cause slaking or disintegration of the tile shall be valid ground for rejection, unless satisfactory proof be submitted that the tiles are permanent and durable, and that the objectionable minerals are not present in quantity or condition to work damage.

The physical tests of the tile shall include strength and absorption tests made in accordance with the standard specifications for drain tile adopted by the American Society for Testing Materials in 1916. The average ordinary supporting strength shall be not less than 800 pounds per linear foot. The average absorption by the boiling test shall not exceed 11 per cent for shale and fire-clay tile, or 14 per cent for surface-clay tile. Tile made of mixed clays shall conform to the absorption requirements for surface-clay tile when the proportion of surface clay is 75 per cent or more, and to the requirements for shale and fire-clay tile for other proportions.

All tile shall be inspected visually (1) to cull and reject imperfect individual tiles, and (2) to determine whether the tiles, independently of meeting the chemical and physical requirements, comply with the specifications of general properties, especially as stated hereinafter.

The bore of all tile shall be approximately circular, the tile shall be approximately straight, and the ends of the tile shall be so regular and smooth as to readily admit of making joints by turning and pressing together adjoining tile.

The sizes of drain tile shall be designated by their interior diameter.

The tile shall have a minimum length of 12 inches.

The tile shall be substantially uniform in structure throughout, as determined by an examination of fractured surfaces.

The tile shall have a clear ring when stood on end and while dry tapped with a light hammer.

The tile shall be reasonably smooth on the inside.

The tile shall be free from cracks and checks extending into the body of the tile in such manner as to decrease the strength appreciably. Tile shall not be chipped or broken in such manner as to decrease the strength materially or to admit earth to the drain.

The tile shall not vary from straight by more than 5 per cent of its length. The maximum and minimum diameters of the same tile, or the average diameter of adjoining tile shall not differ by more than 85 per cent of the thickness of the tile wall. The average diameter of a tile must not be less than 95 per cent of the specified diameter. Exterior blisters, lumps, and flakes which do not weaken the tile and are few in number will be allowed, but only when their thickness does not exceed 25 per cent of the thickness of the tile wall and when their diameters do not exceed 20 per cent of the internal diameter of the tile.

The vendor may appeal from decisions of the inspector on questions of strength or structure when such decisions are based on visual inspection alone, in which case the point at issue shall be determined by standard physical tests, the cost of which shall be paid by the appellant if the inspector was right, or by the purchaser if his inspector was in error.

CEMENT OR CONCRETE TILE.

Wherever cement or concrete tile is called for the tile used shall be equivalent in all respects to the quality and strength of clay drain tile, and shall conform to Specification C4–14 of the American Society for Testing Materials.

CONSTRUCTION.

SIDE DITCHES.

The side ditches, when completed, shall have the general cross section indicated on the plans, and shall confirm in all respects to the lines and grades furnished by the engineer. Where the exact cross-sectional dimensions are not indicated on the plans for each particular section of the road, these dimensions will be fixed by the engineer, with a view to providing adequate drainage without erosion, and shall be strictly observed by the contractor.

In making excavations for side ditches care shall be exercised to see that the earth is not disturbed below the proposed bed of the ditch, and wherever it is necessary to fill in at the sides of a ditch, the material shall be thoroughly tamped as it is deposited so that it will offer practically the same resistance to erosion as the rest of the ditch bed. The ditch, when completed, shall present a smooth uniform bed and shall be kept free from obstructions during all subsequent stages of the work.

The material excavated from side ditches will be paid for at the price bid for ditch or gutter excavation.

COBBLE GUTTERS.

Cobble gutters shall be constructed as shown on the plans or as directed by the engineer in writing, and, when completed, shall conform in all respects to the required cross section, line, and grade. The method of construction shall be as follows:

TRENCH.

Along the line of the gutter, as staked out by the engineer, a trench shall be excavated to the full width of the gutter and to a depth of 12 inches below the gutter grade. When complete, the trench shall be true to line and grade and the bottom shall be compacted and firm, and wherever filling is necessary in order to bring any part of the trench to the required cross section, the material filled in shall be thoroughly tamped.

FOUNDATION.

Upon the bottom of the trench, prepared as described above, shall be spread a layer of crusher-run stone or gravel, such that when thoroughly tamped and compacted it will have a depth of 6 inches.

After the foundation material is spread to the necessary depth it shall be thoroughly compacted, by tamping, or otherwise, until the upper particles are not disturbed by men walking on the surface of the foundation. The foundation, when complete, shall be approximately parallel to the surface of the finished gutter.

SAND BEDDING.

After the foundation has been prepared as above described it shall be covered with a layer of bedding sand. This layer shall have a loose depth of about 2 or 3 inches as may be required to bring the gutter stones which are bedded in it to the required cross section.

SETTING COBBLES.

In setting the cobbles those which are largest and most nearly perfect shall be picked out and set in the edges and middle row of the gutter. All of the

cobbles shall be firmly bedded in the bedding sand and shall fit snugly, one against the other. They shall be set with their longest dimensions lengthwise of the gutter and shall be so arranged as to break joints roughly. As the setting proceeds each cobble shall be rammed with a hand rammer weighing not less than about 20 to 30 pounds until it no longer yields under the rammer, and any irregularities that may be caused by ramming shall be corrected by taking up and resetting the affected portion. When the cobbles have been set and rammed as above described the gutter shall have the required cross section and shall present a uniform appearance. Where the gutter is to be grout filled care shall be exercised in setting and ramming the cobbles to see that the bedding sand is not forced up into the joints above the center of the cobbles.

SAND FILLER.

Where the plans provide for the joints of the cobble gutter to be filled with sand the sand used for this purpose shall conform to the specification for bedding sand and the filling of the joints shall proceed along with the setting and ramming of the cobbles. The sand shall be spread and swept over the surface of the gutter in sufficient quantity to leave a decided surplus on the surface after the joints have been completely filled. While the sand is being spread the entire surface of the gutter shall be repeatedly rammed so as to jar the sand thoroughly into the joints. After the joints are filled the gutter shall be true to the grade and cross section shown on the plans, and all of the cobbles contained in the paving shall be well bedded and so firmly held in place.

GROUT FILLER.

Where the plans provide for the joints of the cobble gutter to be filled with Portland-cement grout the grout used for this purpose shall be prepared by mixing together, by volume, 1 part of Portland cement, 2 parts of sand, and sufficient water to produce a consistency about equal to that of ordinary cream. The sand and cement shall first be thoroughly mixed dry, and the water shall then be admixed. After the grout is mixed it shall be kept constantly agitated until it has all been taken from the containing vessel and used in the joints. At the time the grout is applied the joints shall be entirely free from sand or other foreign material which extends above the center of the cobbles. The grout shall be repeatedly applied and swept back and forth over the surface of the gutter with a suitable broom or squeegee until the joints are filled flush and the surface of the gutter presents a smooth uniform appearance.

After the grouting is completed as above described the gutter shall be protected for at least two weeks until the grout hardens. In case drying weather prevails during this period the gutter shall be kept covered with earth or some other suitable material and shall be kept moist by occasional sprinkling with water.

CONCRETE GUTTERS.

Concrete gutters shall conform to the cross-section drawing shown on the plans for such gutters and shall be true in all respects to the line and grade as staked out by the engineer.

TRENCH.

Along the line of the gutter as staked out by the engineer a trench shall be excavated to the full width of the gutter, with allowance for necessary forms, and to such depth, grade, and cross section that when the gutter is constructed,

as hereinafter specified, all parts of it will serve the required dimensions and conform in all respects to the plans and engineer's stakes. Wherever filling is necessary in order to bring any part of the trench to the required cross section, the material filled in shall be thoroughly tamped, and when the trench is complete it shall have a compacted and firm bed throughout.

FOUNDATION.

(If the climatic and subgrade conditions are such as to make a crushed-stone or gravel foundation necessary, the specification already given for the foundations of cobble gutters may be inserted here.)

FORMS.

After the trench and foundation have been prepared as above specified, suitable forms of either wood or steel shall be provided to receive the concrete paving. The top edges of the forms shall conform accurately to the line and grade required for the gutter. On curves in the alignment of the gutter the form sections shall be sufficiently short to give the appearance of a continuous arc rather than a succession of chords. The forms shall be sufficiently well braced to overcome all tendency to bulge out when the concrete is placed against them and shall have a bearing sufficiently uniform and stable to prevent all sagging while the concrete is being struck off and tamped. The bracing shall be so arranged as not to interfere in any way with the striking off and finishing of the gutter. The forms shall be clean when used and shall be smooth surfaced for all exposed faces.

CONCRETE.

The concrete shall be mixed in the volumetric proportion of 1 part cement, 2 parts of sand, and 4 parts of coarse aggregate, with sufficient water to produce a mixture of such consistency that the concrete will hold its shape after being placed in the gutter, and finished to the required cross section. The mixing shall be thoroughly and uniformly done, either by hand or in a mechanical mixer previously approved by the engineer. Hand mixing shall be done upon a watertight platform of such area as to afford ample room for turning and mixing the largest batch which it is purposed to mix at any one time without danger of mortar escaping over the edges of the platform. The procedure in mixing concrete by hand shall be as follows for each and every batch:

1. Mix the cement and sand dry until the mixture is of a uniform color throughout.

2. Spread the coarse aggregate over the mixed sand and cement, add water, and turn the whole mass three or more times until every particle of the aggregate is thoroughly coated with mortar.

The turning should be systematically done, beginning at one end and turning outward from the pile. In this way the entire mass is turned over and no core or center left undisturbed. The second turning should be at right angles to the first, and the third again at right angles to the second.

The concrete shall be placed in the forms immediately after the mixing is finished, and shall be spread, struck off, tamped, and finished before sufficient time has elapsed for initial set to begin. The foundation shall be moist when the concrete is placed. The striking off and tamping shall be done with templets shaped to conform with the cross section of the gutter and so operated as to insure a uniform surface. The finishing shall be done with a wooden float and when completed the surface shall present a uniform mortar surface entirely

free from honeycombed spots, and no point in the surface shall deviate from the elevation indicated on the plan by more than one-quarter inch.

JOINTS.

Joints shall be made in the gutter at intervals of approximately 20 feet. The joints shall be one-quarter inch in thickness and shall be made by means of bituminous felt boards, which shall be perpendicular to the center line of the gutter and shall extend entirely through the concrete throughout the width of the gutter.

PROTECTION.

After the gutter is completed as above described the concrete shall be protected from too rapid drying by means of a suitable covering. In drying weather the gutter shall be covered with canvas as soon as it is finished. The canvas shall be spread in such a manner as not to mar the surface of the gutter and shall be left in place for about 24 hours, until the concrete has hardened sufficiently not to be damaged by the spreading of an earth covering. It shall then be removed and the entire surface of the gutter covered with a layer of earth or sand about 2 inches thick. The earth covering shall remain on the concrete and be kept thoroughly moist for a period of two weeks, and during this period the concrete shall not be subjected to loads of any kind.

TILE DRAINS.

Tile drains shall be constructed where indicated on the plans and when completed shall conform accurately to the lines and grades established by the engineer. The work of constructing tile drains shall, in all cases, begin at the outlet end of the drain and proceed uphill.

TRENCH.

Trenches for tile drains shall be excavated to a uniform grade such that when the tile is laid it will rest on the bottom of the trench and have the required elevation at all points, and this shall be assured by means of a taut wire or cord stretched between standards established from the engineer's stakes. The width of the trench shall be such that the tile may be readily laid according to the required alignment without the necessity of gouging into the banks of the trench. The bottom width shall in no case be less than 10 inches. Where stone occurs in the trench it shall be excavated to a depth of at least 6 inches below the bottom of the tile, and the space thus made shall be refilled with earth of suitable character and thoroughly tamped before the tile is laid. Where the bottom of the trench is not sufficiently stable, in the judgment of the engineer, to support the tile without danger of unequal settlement 1 by 6 inch wooden boards shall be placed flat in the trench for the tile to rest upon. Where boards are required, the contractor will be paid for the actual cost of the boards delivered on the work and for the work of placing them, plus 10 per cent.

LAYING THE TILE.

In laying the tile the successive sections shall each be turned until the abutting ends fit closely together, and such small openings as may be unavoidable at the joints shall be made to come at the bottom. Any opening more than one-quarter inch wide shall be covered with either broken tile or cement mortar. Wherever two drains come together the junction shall be made by means of T or Y branches and not by cutting two straight sections of tile to fit at an angle.

Where curves occur in the alignment the tile shall be laid accurately to the arc of the curve, and if straight sections are used the joints shall be covered with broken tile or cement mortar.

As soon as the tile is laid as above provided and approved by the engineer, it shall be covered to a depth of about 6 inches with earth which contains no stones larger than 1 inch in diameter and which shall be thoroughly tamped as it is placed. The earth used for this purpose shall be moist when it is placed over the tile and shall be of such quality that it will not run into the tile through the joints. The covering shall be very carefully done so as not to disturb the tile in any way.

After the tile has been carefully covered as above provided, the entire trench shall be back filled. The material used for back filling shall be thoroughly tamped as it is deposited in the trench, and if the engineer so requires, the material of the back fill shall be heaped above the proposed surface over the trench so as to allow for subsequent settlement.

OUTLET.

Tile drain outlets shall be protected with head walls as shown on the plans, and shall be covered with suitable gratings of iron or steel. The upstream end of the drain shall be filled with stone, concrete, or some other durable material which will prevent earth from entering the drain at this point.

ALTERNATE SPECIFICATION FOR BACK FILLING THE TRENCH AROUND AND OVER A DRAIN THROUGH STIFF CLAY.

Before the tile is laid the bottom of the trench shall be covered with a 2-inch layer of gravel or crushed stone of such size that all would pass through a 1½-inch mesh screen and be retained on a one-half inch mesh screen.

(Insert specification for laying tile.)

After the tile is laid as above specified it shall be covered to a depth of 1 foot with gravel or crushed stone of the kind specified for the bottom layer. This covering shall be thoroughly tamped over and around the tile, but in such a manner as not to disturb the tile in any way. The trench shall then be filled to the required depth with gravel or crushed stone of the size elsewhere defined in these specifications for "No. 1 stone," and the entire back fill shall be thoroughly tamped as it is deposited in the trench. The work of making the back fill shall be so carried on as to prevent sand, silt, earth, or other foreign material from getting into either the drain or the interstices of the back fill, and in case this requirement is not observed the contractor may be required to rebuild the drain entirely at his own expense.

GRADING.

Grading shall include the moving of all earth, stone, and any other material that may be encountered, all filling, borrowing, trimming, picking down, shaping, sloping, and all other work that may be necessary to bring the road and subgrade to the required grade, alignment, and cross section, the clearing out of waterways and old culverts, the excavation of all necessary drainage and outlet ditches, the grading of a proper connection with all intersecting highways, the grubbing up and clearing away of all trees, stumps, and bowlders within the lines of the improvement, and the removal of any muck, soft clay, or spongy material which will not compact under the roller, so as to make a firm, unyielding subgrade.

All trees, stumps, and roots within the limit of the improvement shall be grubbed up so that no part of them shall be within 6 inches of the surface of the ground or within 18 inches of the surface of the subgrade.

Embankments shall be formed of good, sound earth and carried up full width. The earth shall be deposited in layers not more than 1 foot in thickness, and each layer shall be rolled or otherwise suitably compacted by distributing traffic uniformly over the surface until thoroughly compacted.

All existing slopes and surfaces of embankments shall be plowed or scarified where additional fill is to be made, in order that the old and new material may bond together. When sufficient material is not available within the fence lines to complete the embankments, suitable borrow pits, from which the contractor must obtain the necessary material, will be designated by the engineer. If there is more material taken from the cuts than is required to construct the embankments as shown on the plans, the excess material shall be used in uniformly widening the embankments or shall be deposited where the engineer may direct. Wherever embankments are formed of stone the material shall be carefully placed, so that all large stones shall be well distributed and the interstices shall be completely filled with smaller stone, earth, sand, or gravel, so as to form a solid embankment.

During the work of grading, the sides of the road shall be kept lower than the center and the surface maintained in condition for adequate drainage.

The grading of any portion of the road shall be complete before any surfacing material is placed on that portion; and where the plans do not call for any substantial change in the grade of any existing section of the road the surface shall be completely scarified to a depth of 3 inches or more before the subgrade is prepared.

SUBGRADE.

The subgrade, or that portion of the road upon which the roadway is to be constructed shall consist of good, sound earth brought to the proper elevation, alinement, and cross section, and shall be rolled until firm and hard. The rolling shall be done with a power roller, weighing not less than 10 tons and not more than 15 tons. Should earth be encountered which will not compact by rolling, so as to be firm and hard, it shall be removed and suitable material put in its place, and that portion of the subgrade shall be again rolled. When the rolling is completed the surface of the subgrade shall conform to the cross section shown on the plans, and shall have the proper elevation and alinement, and shall be so maintained until it is covered by the foundation or road crust.

CRUSHED-STONE FOUNDATION.

Where a crushed-stone foundation is called for on the plans it shall be constructed after the curbs are set and in two courses of such thickness that the finished foundation will have the required depth shown on the plans.

The first course of stone shall consist of a single layer of No. 1 stone spread uniformly to a depth of not more than 6 inches before compacting. The stone shall be spread by hand from dumping boards or from dump wagons of a type that will distribute each load of stone evenly over that part of the subgrade to be covered by the load.

After the crushed stone of the first course has been spread to the required depth, it shall be rolled until it is thoroughly compacted and firm with a three-wheeled power roller weighing not less than 10 tons and not more than 15 tons. The rolling shall begin at the curbs and progress gradually toward the crown. All irregularities and depressions that may develop shall be immediately cor-

rected with No. 1 stone, and the rolling shall continue until the stone is well compacted and the surface is uniform in grade and cross section.

The second course of stone shall consist of a single layer of No. 2 stone spread uniformly to a depth not exceeding 4 inches. The stone shall be spread and rolled in the manner prescribed for the first course. When completed the surface of the second course of crushed stone shall be smooth, firm, well compacted, and continuous, and shall have the cross section and grade indicated by the drawings.

After the second course of stone has been spread, rolled, and completed as above specified, screenings shall be spread uniformly over the surface to a depth of approximately one-half inch. The spreading shall be done with shovels from piles along the road, from dumping boards, or from carts. In no case shall an entire load of screenings be dumped directly upon the second course.

After the screenings are spread they shall be dry rolled until the voids of the second course are filled. The foundation shall then be sprinkled with water from properly constructed sprinkling wagons and rolled with a power roller of the type and weight specified for the first course. The amount of water used shall be sufficient to wet the stone thoroughly, but shall be put on in such quantity and manner as not to wet and soften the subgrade. Screenings shall be added and the sprinkling and rolling continued until the surface ceases to show the marks of the roller and a grout of water and rock dust flushes ahead of the roller.

After the foundation is completed, as above specified, no materials or traffic shall be placed or allowed upon it for at least 24 hours.

TELFORD FOUNDATION.

The Telford foundation shall conform to the cross-section drawings shown on the plans and when completed shall be true in all respects to the line and grade as staked out by the engineer.

TELFORD STONES.

The stone used shall be sound and durable and, in the judgment of the engineer, equal in quality to that obtained from the ——— quarry located at ———. The individual blocks shall be approximately rectangular in shape and shall conform to the following limiting dimensions:

Depth—Equal to the depth of the foundation as shown on the plans.

Length—Not less than the depth and not greater than one and one-half times the depth.

Width—Not less than one-half the depth and not more than the full depth.

SETTING THE TELFORD.

The stones shall be set by hand with their long dimensions at right angles to the direction of the road and in approximately straight courses. They shall break joints roughly in the courses and shall fit in snug contact, one against the other. Each stone shall rest on its broadest edge and shall be rammed to a firm uniform bearing on the subgrade.

After the stones are set as above provided all interstices that appear in the surface of the foundation shall be filled with spalls which shall be firmly wedged into place by means of a hand hammer. All projecting stones which extend more than 1 inch above the established surface of the foundation shall

be broken off as the wedging proceeds. When this process is completed the foundation shall present a true and uniform appearance and shall contain no stones that may be loosened or shaken with the hand or foot.

ROLLING.

After the foundation has been wedged and surfaced as above provided it shall be thoroughly rolled with a roller weighing not less than 10 tons. Any depression that may develop under the roller shall be corrected by taking up and resetting the affected portion, and the portion thus reset shall be again rolled. When the rolling is finished the foundation shall be uniformly of the required grade and cross section and every stone which it contains shall be firmly wedged in place, and the surface shall be free from all loose stone or other material which would be objectionable in the road crust.

CONCRETE FOUNDATION.

Upon the subgrade prepared as herein specified shall be laid a concrete foundation of the width and thickness shown on the plans. The subgrade shall be wet but not muddy when the concrete is placed upon it. The concrete shall be composed of the following materials, by volume: One part cement, 3 parts sand, and 5 parts of gravel, crushed stone, or crushed slag, and sufficient water to form a quaky mass, and shall be thoroughly mixed in a machine mixer of the batch type, so constructed and operated that the thorough mixing of the materials will be assured. The concrete shall be so delivered to its place on the subgrade as not to cause or permit any separation of the materials. Wheelbarrows or other devices used for measuring the materials shall be of uniform capacity. The concrete shall be deposited in place immediately after it is mixed and shall be well compacted as fast as it is placed. The top surface shall be smoothed by troweling with shovels or by some other means approved by the engineer, and when completed shall not vary more than one-half inch from the proper shape and grade, as shown on the plans and profiles. The concrete foundation shall be kept wet by sprinkling with water during the first four days after it is laid. No hauling over it or rolling or tamping of brick upon it will be permitted for seven days after it is placed, and during this time it shall be properly protected from injury. Concrete shall not be mixed when the temperature of any of the materials is less than 35° Fahrenheit. Concrete shall not be used after it has begun to show evidence of setting, and no concrete which has once set shall be used as material for mixing a new batch.

FLANGE CURBS.

Concrete curbs shall be built on the foundation as shown on the plans. The concrete shall be composed of the following materials, by volume: One part of cement, 1½ parts of sand, 3 parts of gravel or crushed stone, and water. The materials shall be thoroughly mixed in a machine mixer of the batch type or by hand. If the mixing is done by hand, it shall be done upon a water-tight platform with raised edges, in the following manner: The sand and cement shall be thoroughly mixed dry and spread out upon the mixing platform, and upon this dry mixture shall be spread the coarse aggregate. Water shall then be poured over the aggregate in such an amount that the resultant concrete will be of a quaky consistency. The whole mass shall then be turned with shovels until all of the materials are thoroughly mixed. The concrete for the curb shall be placed upon the foundation before the concrete of either the curb or the foundation has taken its initial set, and care shall be taken, such as rough-

ening the concrete of the foundation and tamping the concrete of the curb, to insure that the curb will be firmly bonded to the base. The concrete shall be well tamped and spaded along the forms, so that when they are removed there will be no open and porous places on the sides of the curb. The top surface of the curb shall be floated or troweled to a smooth finish. The forms for the curb shall be smooth, clean, free from warp, and of sufficient strength to resist springing out of shape. They shall be well staked and braced, and the top edges shall be at the same height and set true to line. To protect the curb from drying out too rapidly it shall, within 12 hours after it is placed be covered with gunny cloth, which shall be kept wet for five days.

SEPARATE CONCRETE CURBS.

Where the plans call for concrete curbs separate from the foundation they shall be constructed before the subgrade is finally completed and shall have the cross section shown on the plans. Such curbs shall be constructed in sections not less than 6 feet and not more than 12 feet in length and shall be true to grade and alignment.

The specification already given for concrete curbs constructed in combination with the foundation shall also apply to curbs constructed separate from the foundation as regards proportioning, mixing, and placing the concrete, constructing the forms, and all other features of construction which are not covered on the plans or in this specification.

STONE CURBS.

Where stone curbs are required, they shall be hauled and set before the subgrade is finally completed. The curbs shall be set to line and grade and shall be securely bedded in broken stone, gravel, or firm earth. In preparing the trenches for the curbs great care shall be exercised to see the material upon which the curb is to be set is well compacted, firm, and hard.

Stone curbing shall be quarried from hard, tough, homogeneous stone. The individual blocks shall have the cross section shown on the plans and shall be not less than 4 feet in length. Each block shall be free from seams and all other imperfections and shall be neatly dressed and finished on all exposed faces.

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